INTERNATIONAL STANDARD

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Tolerances for building — Methods of measurement of buildings and building products —

Part 1: Methods and instruments

Tolérances pour le bâtiment — Méthodes de mesure des bâtiments et des produits pour le bâtiment —

Partie 1: Méthodes et instruments

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

International Standard ISO 7976-1 was prepared by Technical Committee ISO/TC 59, *Building construction.*

Users should note that all International Standards undergo revision from time to time and that any reference made herein to any other International Standard implies its latest edition, unless otherwise stated.

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Contents

Tolerances for building — Methods of measurement of buildings and building products —

Part 1: Methods and instruments

1 Scope and field of application

This International Standard gives some alternative measuring methods for the determination of shape, dimensions and dimensional deviations of buildings and building products which are relevant to fit. The methods can also be applied when accuracy data are being collected in factories or on building sites.

Information is given about deviations of parts of buildings or of building products which can be determined with the equipment described.

The measuring methods concern primarily those objects the faces of which are rectilinear in shape and which have a modulus of elasticity larger than 35 kPa, for example concrete, wood, steel, hard plastic. Building products consisting of glass wool and similar soft materials are not the subject of this International Standard.

Rules for quality control in all stages of measurement such as frequency checks, place, time, etc., are not covered by this International Standard.

Part two of this International Standard gives the position of measuring points to be used in the measurement described in this part.

To facilitate cross-referencing, the same numbering is used in the two parts of this International Standard.

2 References

ISO 4464, *Tolerances for building — Relationship between the different types of deviations and tolerances used for specification.*

ISO 7078, *Building construction — Procedures for setting out, measurement and surveying — Vocabulary and guidance notes.*

ISO 7976-2, *Tolerances for building — Methods of measurement of building and building products — Part 2: Position of measuring points.*

ISO 8322, *Building construction — Measuring instruments — Procedures for determining accuracy in use —*

Part 1: Theory. 1)

Part 2: Measuring tapes. 1)

Part 3: Optical levelling instruments. 1)

Part 4: Theodolites. 1)

Part 5: Optical plumbing instruments. 1)

Part 6: Laser instruments. 1)

Part 7: Instruments when used for setting out. 1)

Part 8: Electronic distance measuring instruments. 1)

3 General

3.1 Methods of measurement

The methods of measurement refer to the main dimensions of building products, distances between such products and their geometrical deviations. They may, however, also be applied to parts and to subdivisions in building products.

The items to be measured should be supported as they will be supported in use. When this is impractical, the support conditions should be agreed in the measuring schedule. If components are measured whilst they are in a manufacturing jig or mould, this should be noted. Flexible components should always be fully supported on a flat surface.

For both compliance measurements and for the collection of accuracy data, the measurement procedure should be significantly more accurate than the permitted deviation specified for the manufacturing or construction process to be measured.

1) At present at the stage of draft.

Arrangements which make it possible to check the accuracy of the measurement procedure are an essential part of the method. (See ISO 8322, parts 1 to 8.)

When recording the result of a measurement the following conditions should be reported where appropriate:

- identification of operator, instrument and time;
- position and attitude of the object being measured;
- temperature and moisture content of the object being measured;
- any other matters pertaining to the measurement.

It is usually possible to measure directly on surfaces cast against a smooth mould. Local defects such as pores, burns and casting blemishes shall be avoided in the measurement. They shall not appear as incorrect sizes, but their presence shall be noted. In the case of a surface with a considerable roughness in relation to the permitted deviations, the measurements can be specified to be made with the aid of sufficiently large position pieces placed on the object of measurement.

At the end of each of clauses 4 to 14, there is a table that specifies the following items for each of the measuring operations in that clause:

- the measuring operation;
- limits of measuring accuracy, in terms of the permitted deviation of the item to be measured;
- the measuring range;
- the measuring instrument or tool which can be chosen.

3.2 Influence of deviations from reference conditions

Variations in the ambient conditions from the specified reference values can give rise to errors in the measured size of a dimension. Temperature, especially direct sunshine, is normally the most significant of these ambient conditions.

Other reference conditions such as moisture content of timber and age of concrete components shall be taken into account where appropriate.

The actual temperature of either the object to be measured or the measuring equipment may be difficult to determine in practice since it is unlikely that either will be at uniform temperature and because temperature differentials within the object to be measured or in the equipment will exist. The most satisfactory solution is to allow both the object to be measured and the measuring equipment adequate time to achieve a stable ambient temperature. This temperature can then be measured and allowance made for any variation from the specified reference temperature.

So far as the measuring equipment is concerned, the most likely sources of heat input are from the handling of the equipment and from differences between ambient temperature and the reference condition. The object to be measured is also affected by ambient temperature and may also be subjected to considerable heating during manufacture.

The reference temperature in this example is considered to be 20 °C. The following symbols are used:

t_1 is the temperature of object to be measured, in degrees centigrade;

t_2 is the temperature of measuring equipment, in degrees centigrade;

a_1 is the coefficient of expansion of object to be measured;

a_2 is the coefficient of expansion of measuring equipment;

Δt_1 is the temperature difference from 20 °C of object to be measured ($\Delta t_1 = t_1 - 20$);

Δt_2 is the temperature difference from 20 °C of measuring equipment ($\Delta t_2 = t_2 - 20$);

L is the length being measured.

Then the error in measurement ΔL caused by the temperature differentials Δt_1 and Δt_2 is given by:

$$\Delta L = L\,(a_1\,\Delta t_1 - a_2\,\Delta t_2)$$

Section one : Measuring methods for those measurements which can be carried out both in factories and on building sites

NOTE — Most of the examples concerning components can also be applied to parts executed on site.

4 Sizes of components

This clause describes examples of instruments and measuring methods for the determination of length, width and thickness of components.

Linear dimensions are determined using measuring instruments (with or without the aid of position pieces) cited in clause 15, where typical errors and precautions needed are also indicated.

Special attention should be paid to tension and temperature when measuring with tapes. A tape tensioner applying the reference tension should be used where specified or when the length to be measured exceeds 10 m. It is recommended that the tape is supported in order to reduce the influence of the temperature of the object to be measured (see figure 1). It should be observed that when the tape rests on a building component or a floor, the temperature of this object of measurement can differ from the measured temperature of the surrounding air and hence cause measuring errors (see 3.2). This error can be reduced by supporting the tape. The correct temperature of the tape can be measured with a contact thermometer.

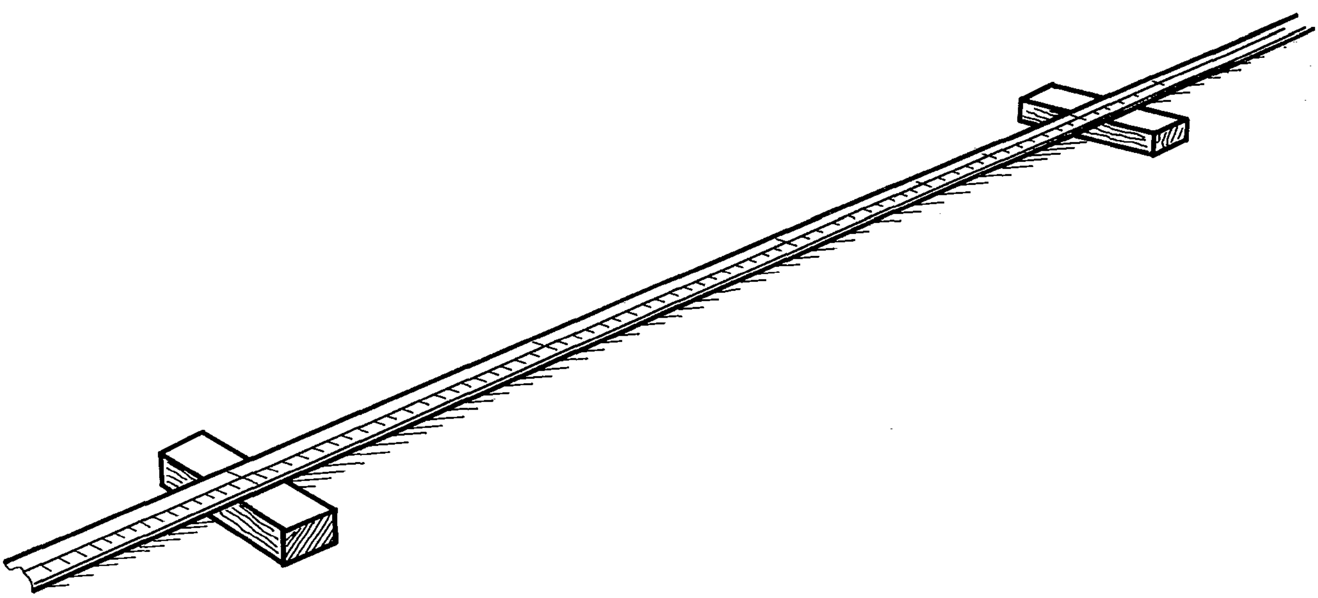


Figure 1

4.1 Length and width

On components which do not have sharply defined edges, position pieces (see clause 15) should be used to improve measuring accuracy. The position pieces should be held or clamped, as necessary for the duration of the measurement, against the appropriate faces of the component in order to define precise edges. An example of the use of corner pieces is given in figure 2.

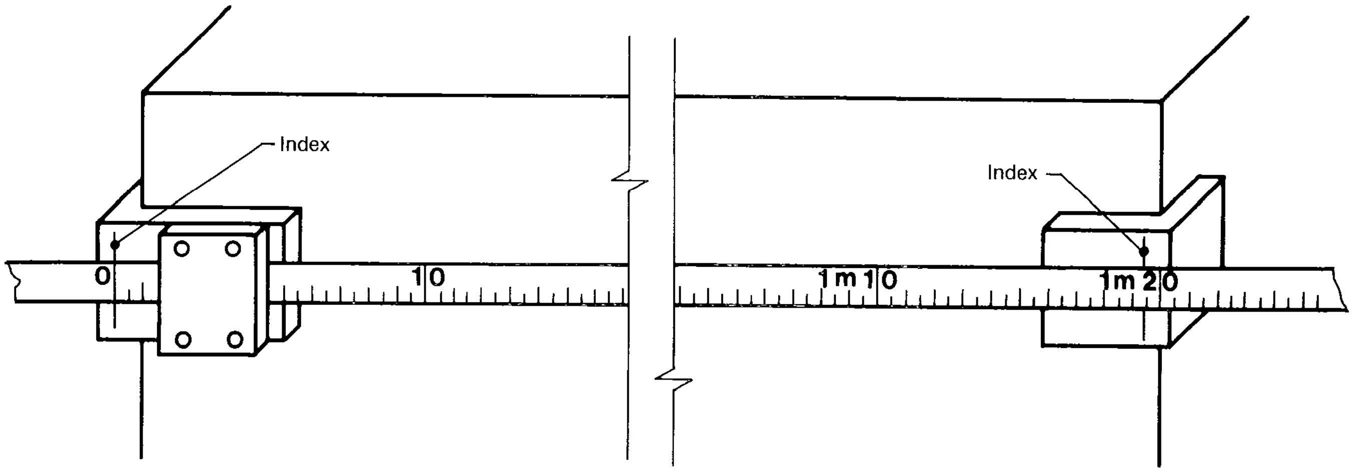
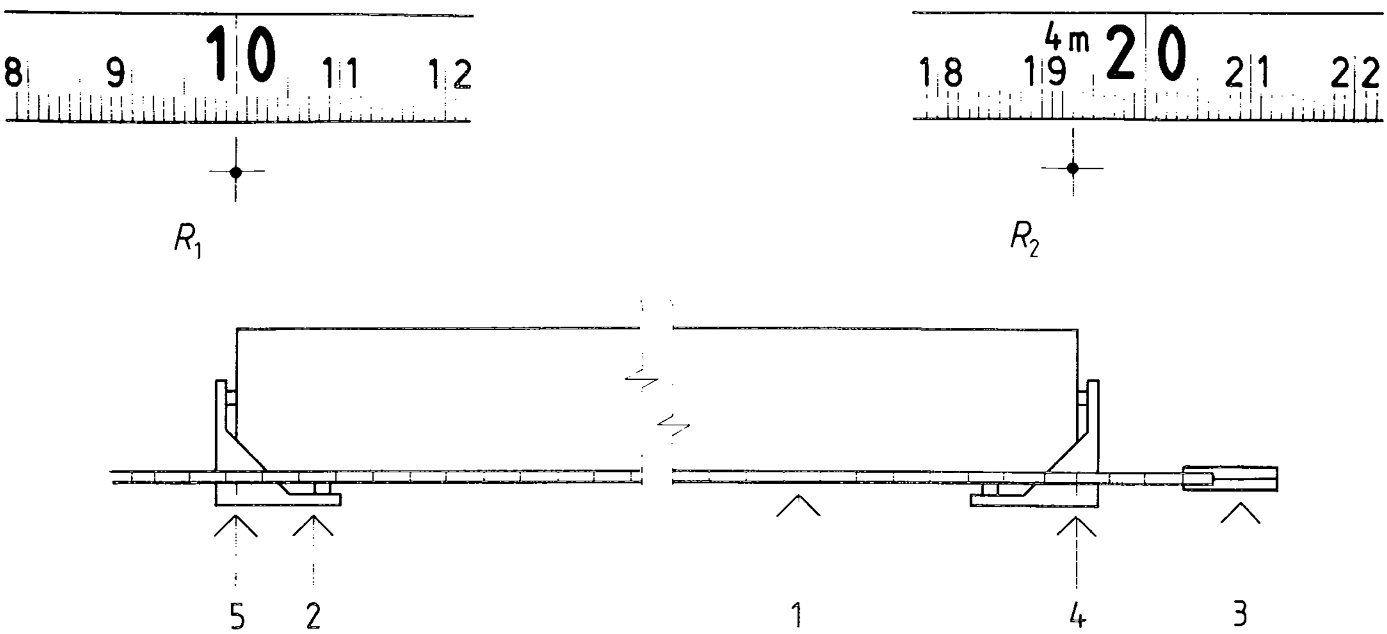


Figure 2



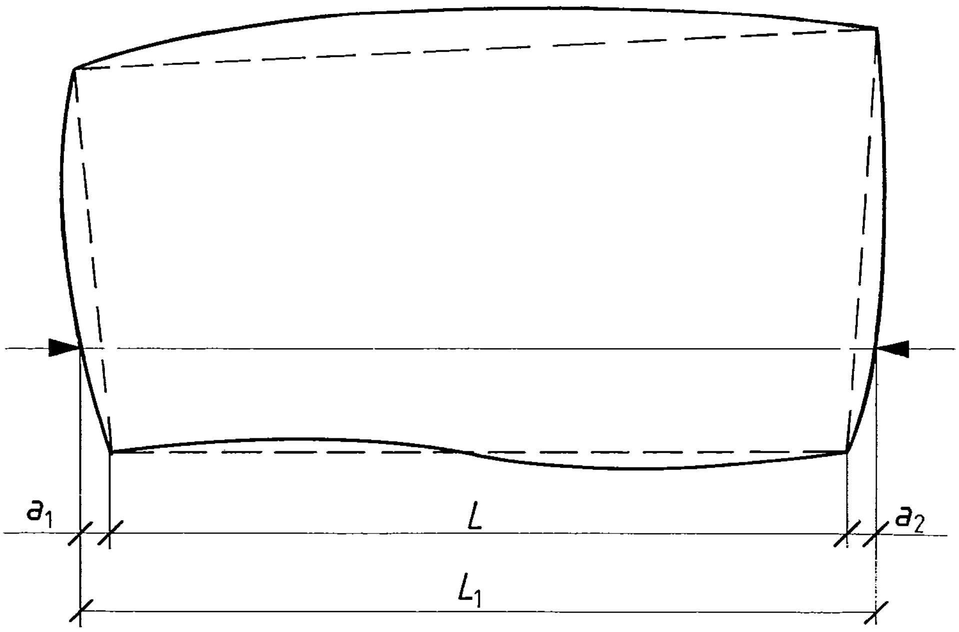
1 : Tape
2 : Corner piece
3 : Tape tensioner
4 : Reading
5 : Reading

Example : R_2 4,193
R_1 − 0,100
L = 4,093

NOTE — When the zero point is at the end of the tape, readings shall be made in two places.

Figure 3

The result of a measurement between opposite points other than corner points can be used as a rough check of the result of the measurement of straightness deviations. (See clause 6 and figure 4.)



$$L_1 = L + a_1 + a_2$$

Figure 4

When measurements are made along curved surfaces, errors arise as the curve AB is always longer than the chord AB. Normal accuracy requirements permit readings to be taken to the nearest millimetre. This implies that in practice some amount of curvature can be allowed. (See figure 5.)

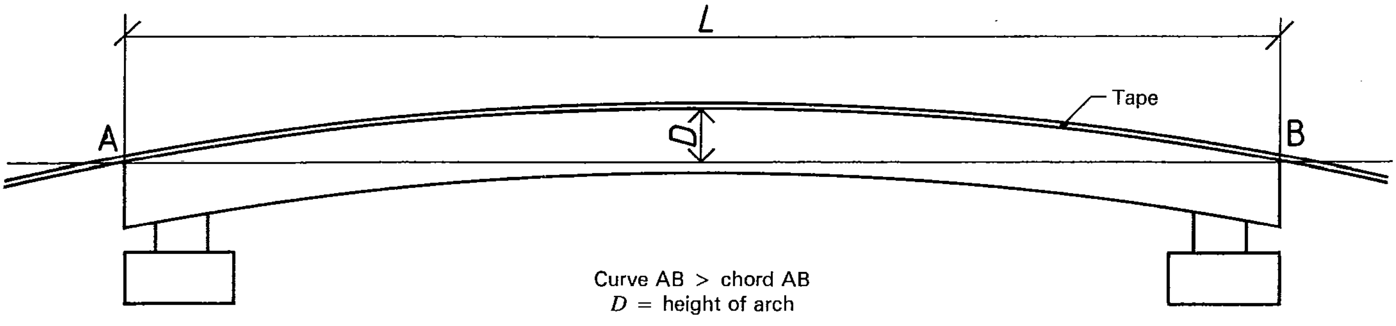


Figure 5

Figure 6 gives a diagram for corrections to be applied when measuring along curved components.

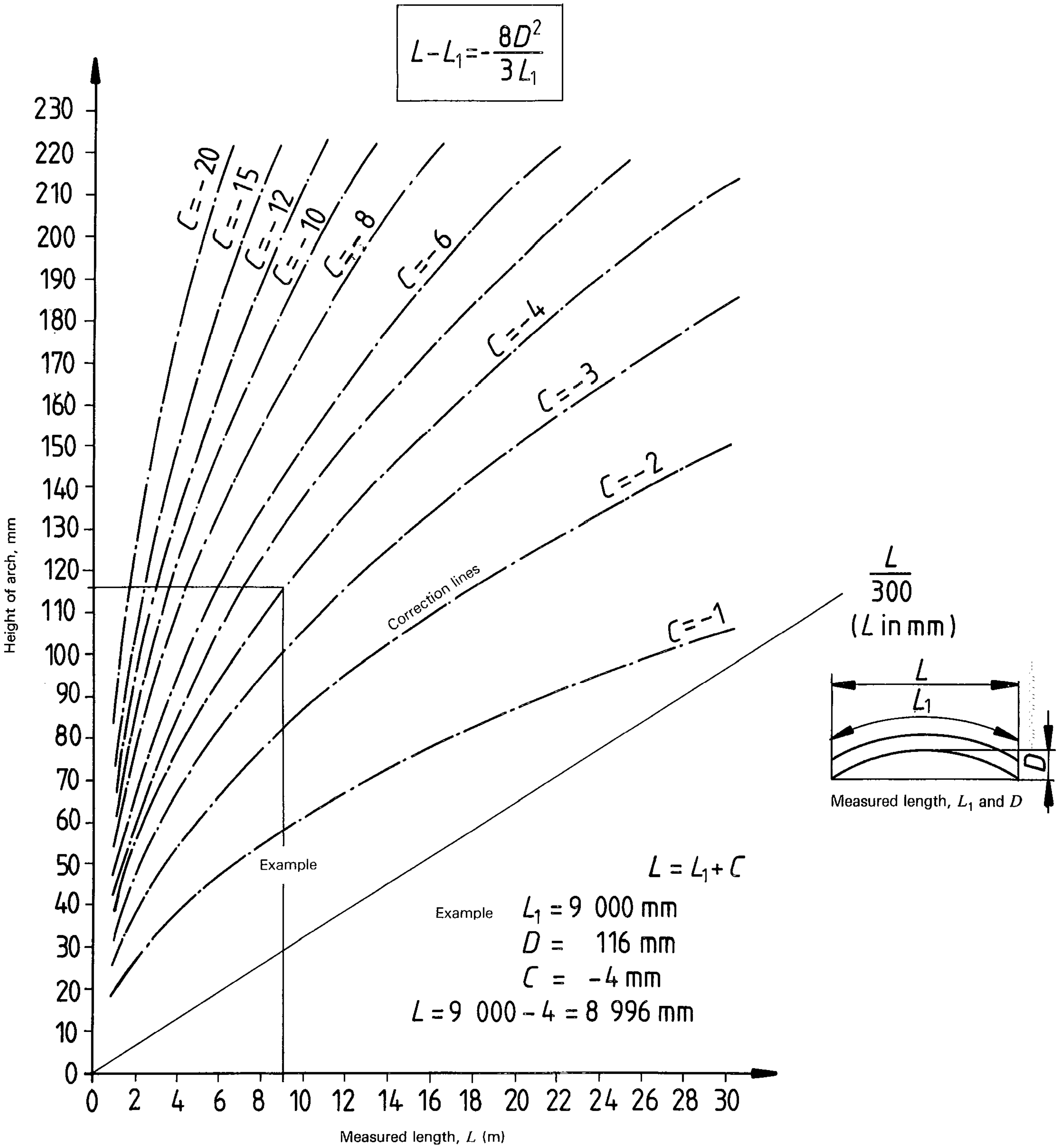


Figure 6

4.2 Thickness or depth

Thicknesses (or depths) of components are determined using instruments cited in clause 15 and in principle carried out in the same way as described in 4.1.

When necessary, corner- and/or edge-pieces should be used.

Instruments with a large contact surface are used for materials with an uneven surface.

Thickness shall be measured perpendicular to at least one of the surfaces of the component. (See figure 7.)

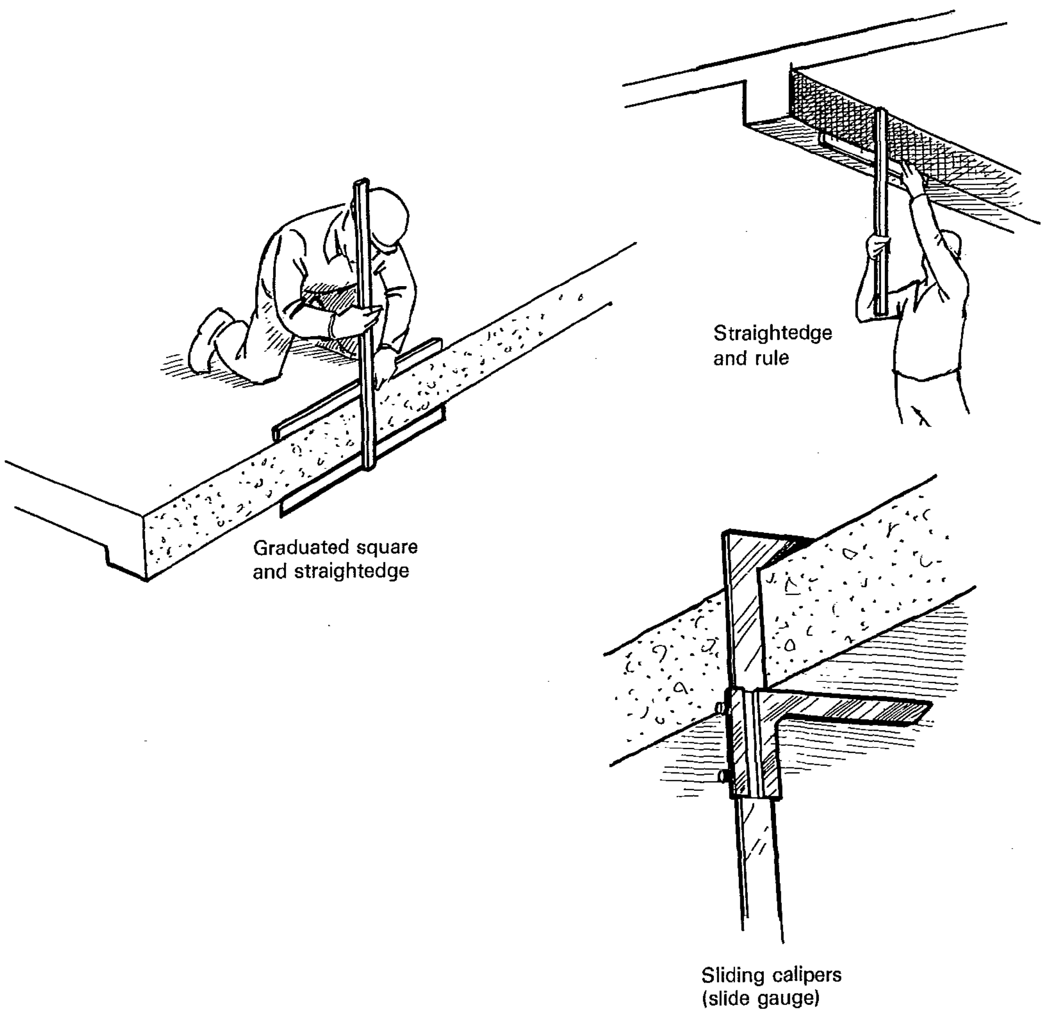


Figure 7

4.3 Accuracy table

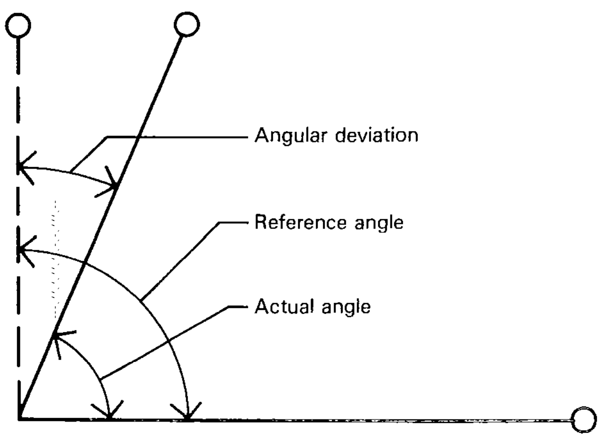
Measuring operation	When values for permitted deviation specified for object exceed:	Measuring range	Measuring instrument or tool
1	2	3	4
Lengths and widths of components (4.1)	± 3 mm ± 3 mm ± 5 mm	< 1 m < 3 m 3 to 10 m	Retractable steel tape Calibrated steel tape Calibrated steel tape
Thickness of components (4.2)	± 0,5 mm ± 1 mm ± 2 mm ± 3 mm ± 5 mm	< 0,1 m 0,1 to 0,5 m 0,5 to 2,0 m < 1 m < 0,5 m	Caliper Caliper Caliper Retractable steel tape Measuring rod and two boning rods

5 Squareness (perpendicularity) of components

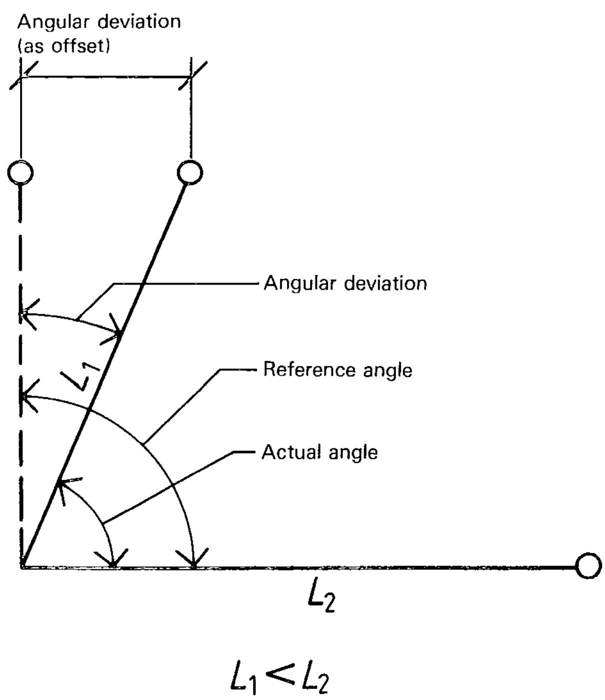
This clause describes examples of instruments and measuring methods for the determination of deviation from squareness (right-angle), but can in principle be applied to any angle.

According to ISO 4464 the angular deviation is described as the difference between an actual angle and the corresponding reference angle.

Figure 8 shows angular deviations expressed in gon or degrees [figure 8a)] or as offsets [figure 8b)].



a)



b)

Figure 8

If alternative b) is put into practice, the angular deviation shall be determined from the shorter side of the angle and shall be measured perpendicular to the corresponding side of the reference angle.

Parallelism deviation, which is another form of angular deviation, is dealt with in 5.2.

Angular deviations are determined using instruments and tools given in chapter 15, with or without the aid of position pieces.

Three methods are described for the determination of deviations from a right-angle in building products. The method chosen depends on the size of the object of measurement.

In figure 9, if b and c < 1 200 mm, a square is used as shown in figure 11. Otherwise, a measuring telescope is used (see 5.1.3) or diagonal measurement (see 5.1.2) is made. Diagonal measurement, however, may only be used when the permitted deviation of the right-angle is more than 5 mm per metre.

The three methods used for determination of angular deviations are explained in the examples below. The deviation is always measured on the shorter leg of the angle and the final result will be the deviation of point B or point C from the required position.

In figure 10, the angles to be measured are those between the lines which connect the corner points (see also figure 16).

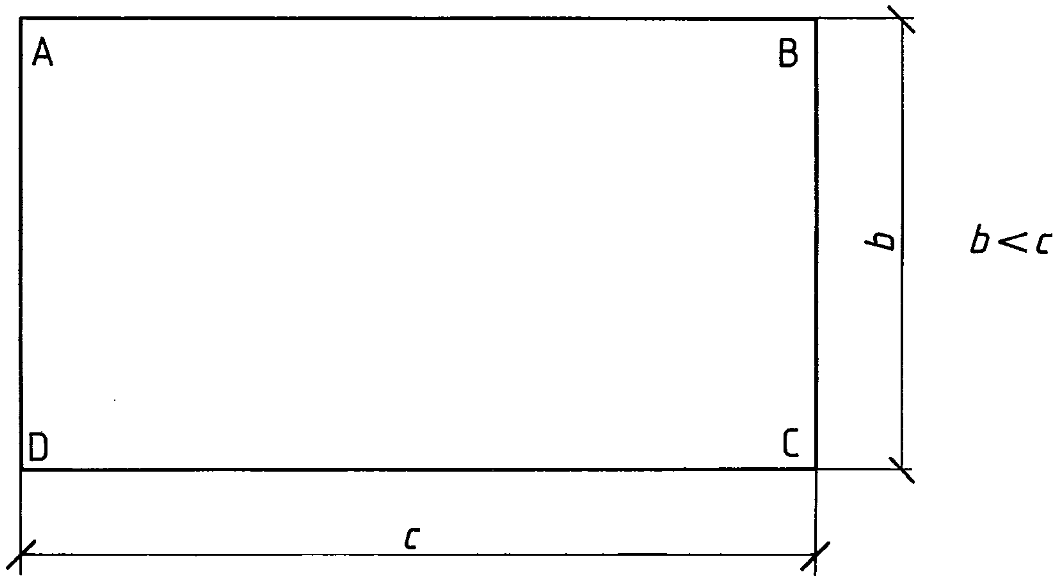


Figure 9

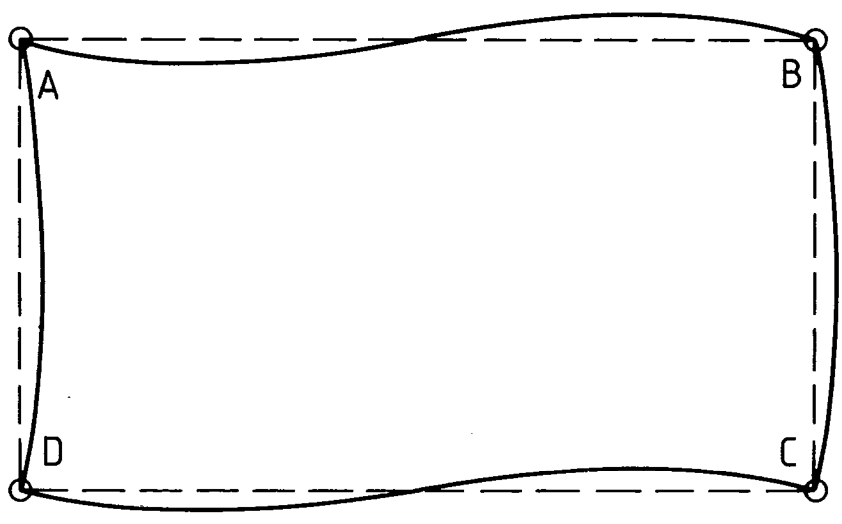
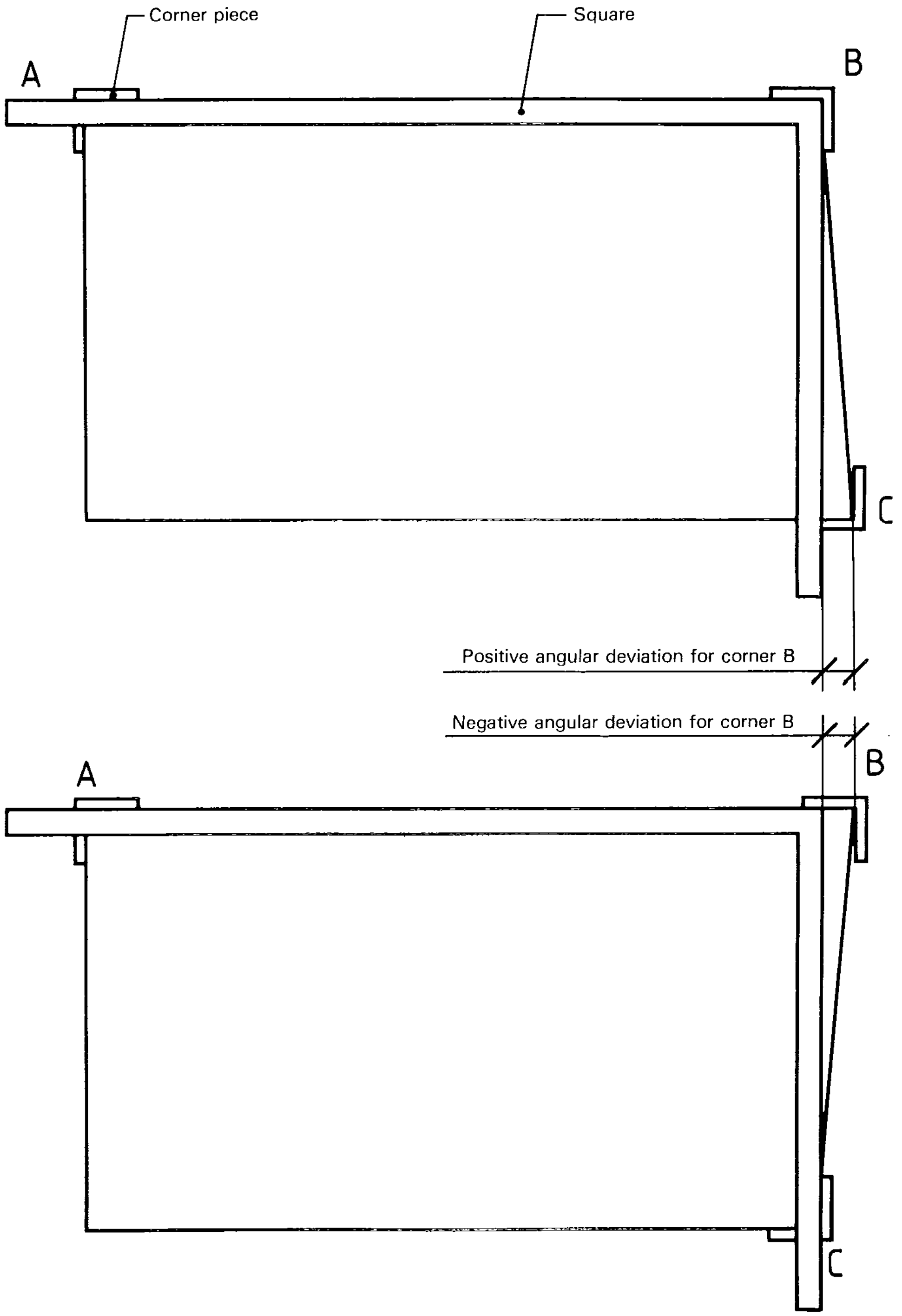


Figure 10

5.1 Angular deviation

5.1.1 Measuring using a square

In figure 11, a square of sufficient size is placed with the longer arm along AB in such a way that the shorter arm touches B or C. The angular deviation of corner B is determined as shown.



Maximum size: 1 200 mm × 1 200 mm
Corner pieces at A, B and C

Figure 11

In figure 12, a square is positioned for measurement of angular deviation. The square rests against the studs S. In order to reduce friction, the arm L_1 is supported on the roller bearing R.

In figure 13, the method in figure 12 can also be used to measure angular deviations on columns.

When using methods shown in figures 12 and 13, the thickness of spacers or studs shall be subtracted from the reading when evaluating the angular deviation.

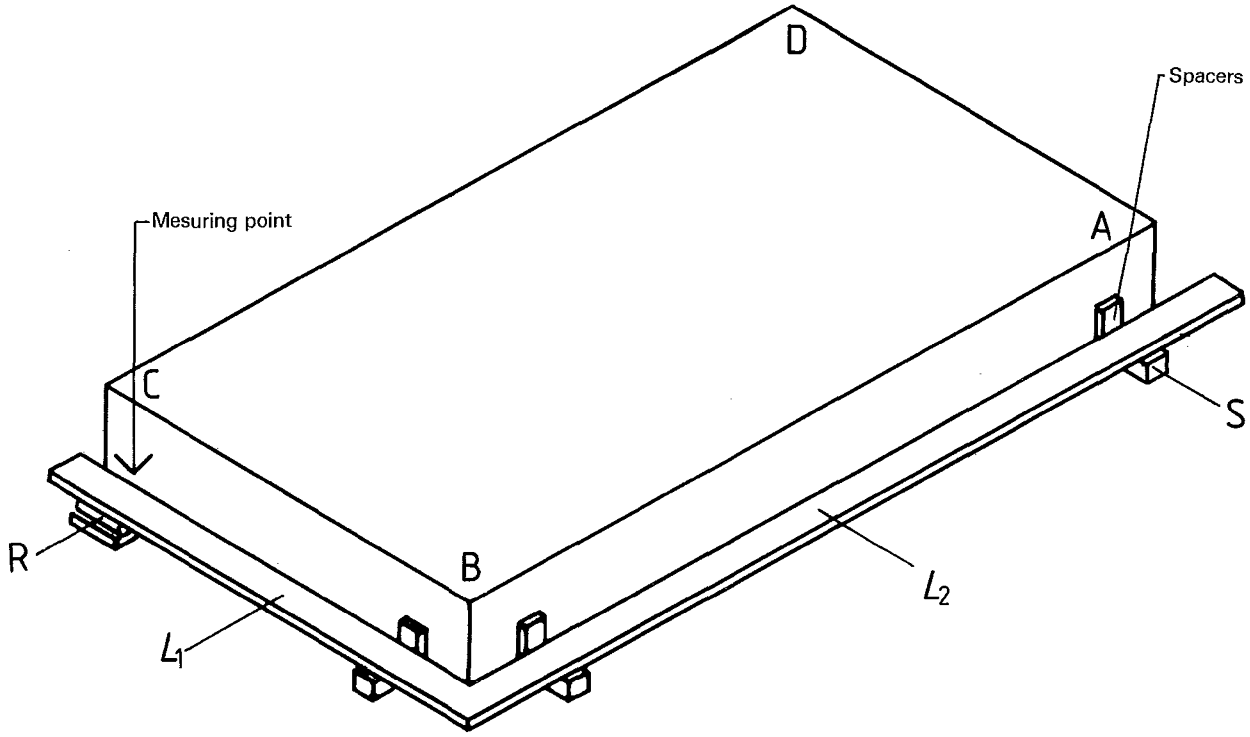


Figure 12

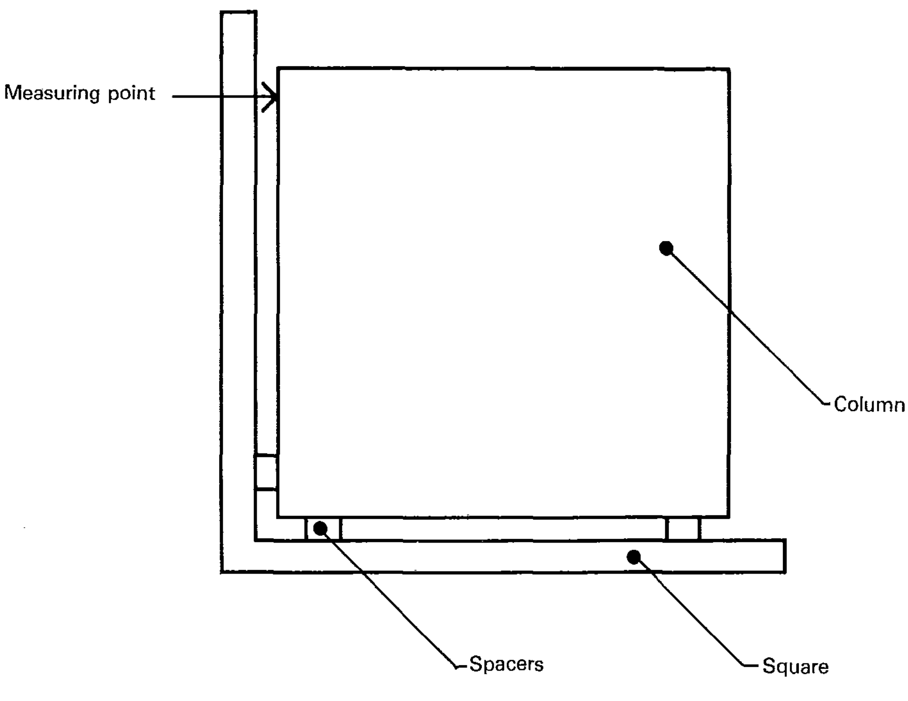


Figure 13

The method in figure 14 can only be used when no straightness deviations occur, as otherwise only the deviations from the right-angle between parts of the surfaces are observed, that is angle ABC and not ABD.

5.1.2 Diagonal measurement

In figure 15, the distances AB, BC and AC are determined with the aid of tapes and corner pieces.

The dimensions of the object to be measured may not exceed the length of the tape and the ratio width/length of the object to be measured shall not be less than 1:2.

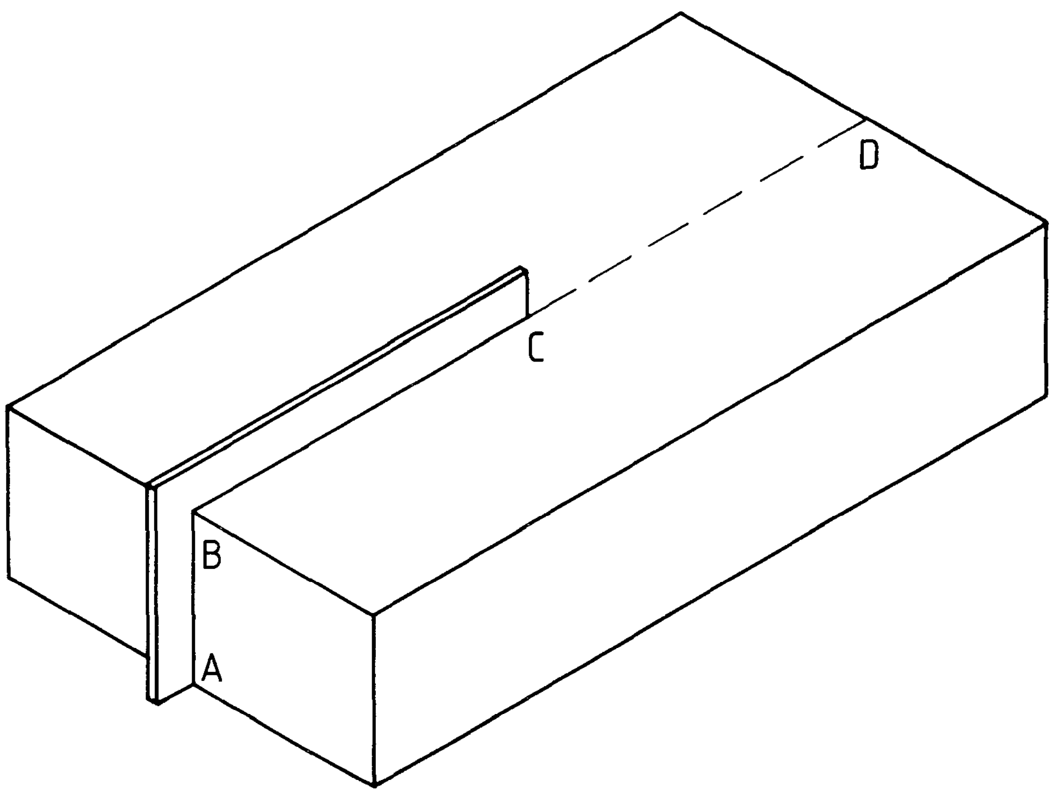
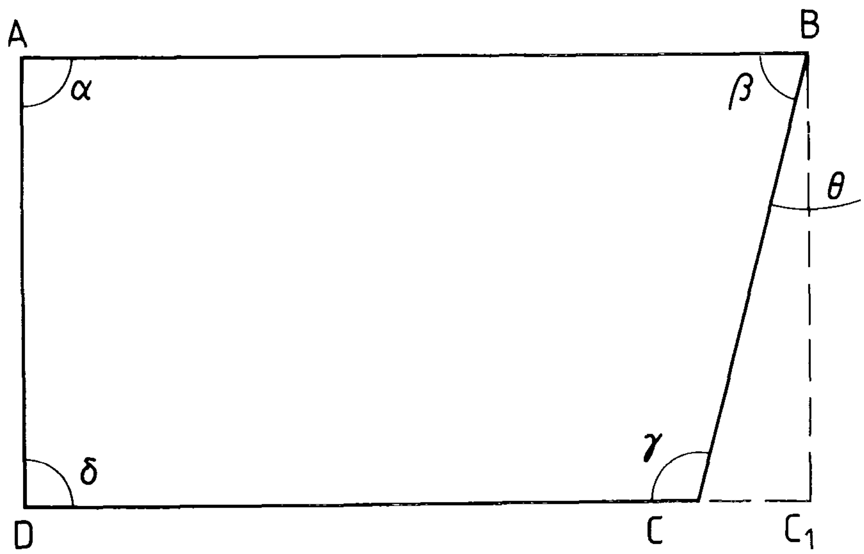


Figure 14



$$CC_1 = \frac{AB^2 + BC^2 - AC^2}{2AB}$$

Figure 15

The angle at point B can be calculated as follows:

$$\cos \beta = \frac{AC^2 - AB^2 - BC^2}{-2\,AB \times BC}$$

This procedure can be repeated for the points A, C and D.

The sum of the angles ($\alpha + \beta + \gamma + \delta$) should be 400 gon or 360°. Any misclosure must be divided equally over the four angles, provided that the misclosure is not more than 0,12 gon (0,11° = 7′) for a component of size about 2 000 mm × 3 000 mm. If the misclosure exceeds this figure, new measurements shall be made.

The angular deviation as an offset (CC_1) can also be determined in relation to the side CB as follows:

$$\beta = 100 \text{ gon} - \theta$$

$$\cos \beta = \sin(-\theta) = \frac{CC_1}{BC} = \frac{AB^2 + BC^2 - AC^2}{2\,AB \times BC}$$

or

$$CC_1 = \frac{AB^2 + BC^2 - AC^2}{2\,AB}$$

5.1.3 Measuring with a measuring telescope

In figure 16, a measuring telescope is positioned at measuring point B and set at zero towards target A. The instrument is then rotated 100 gon (90°) and the deviation at target C is determined using, for instance, a millimetre-scale placed at this point.

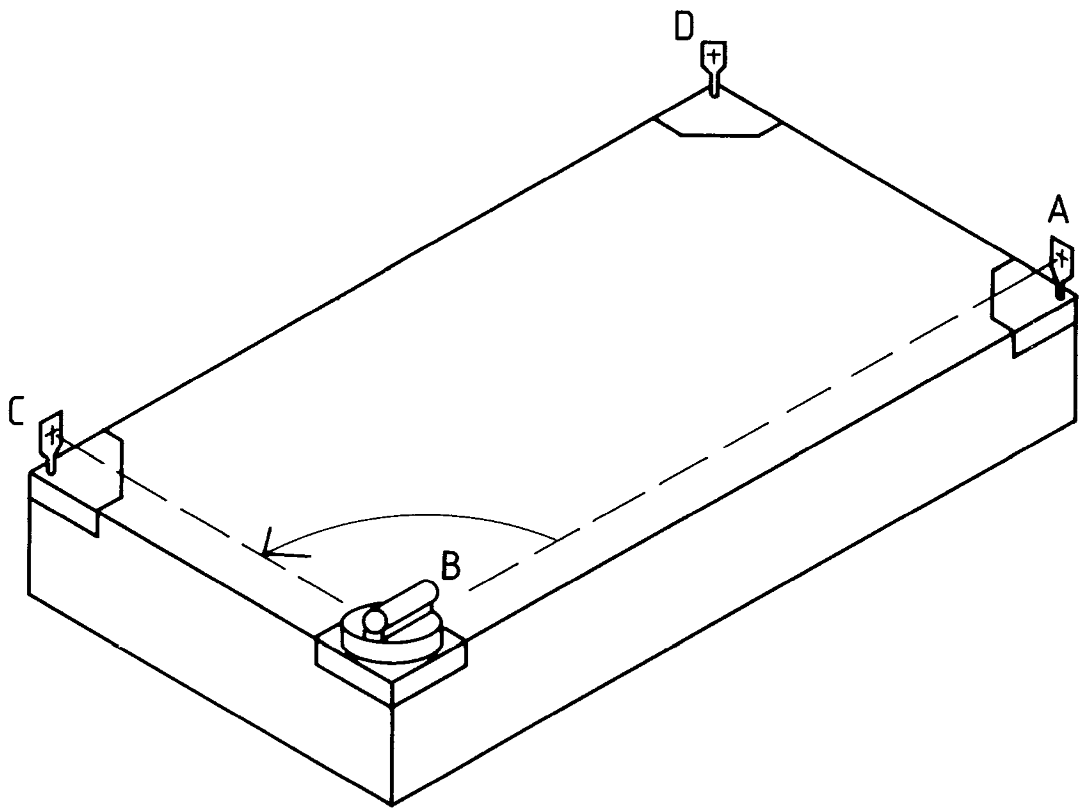


Figure 16

Figure 17 shows a method for the determination of the angular deviation (at B) with the aid of a theodolite (T) the sighting axis of which is brought parallel with BA by turning the theodolite until the readings on the measuring rod (P_1 and P_2) are equal.

The telescope is then turned through 100 gon (90°) and the distances P_3 and P_4 are read off in the telescope from the measuring rod. The distances P_1 to P_4 should range from 500 mm to 1 000 mm. This means that in most cases additional lenses for short-range observation will have to be mounted on the theodolite when reading distances P_1 and P_3.

The offset angular deviation is in this case positive ($P_3 - P_4$).

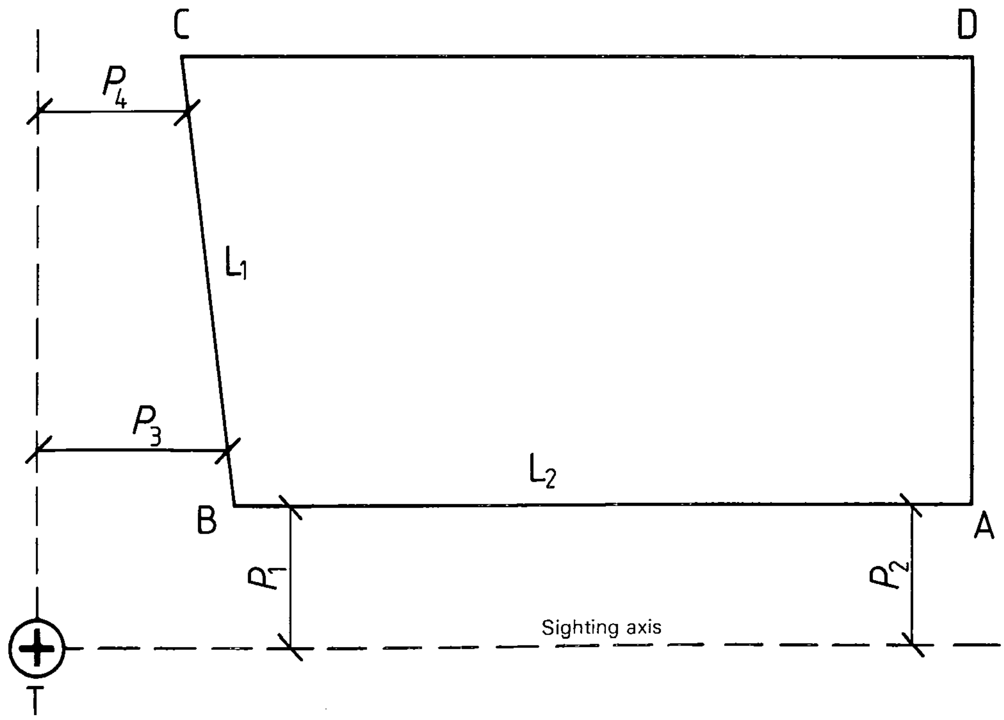


Figure 17

5.2 Parallelism

Parallelism deviation is a form of angular deviation and is the difference between the orientation of the straight line through A and B and the orientation reference line AB_1 through A, parallel to DC (see figure 18). The deviation is measured as the distance between B and B_1 (see ISO 4464).

In figure 18, distances AD and BC are measured from C and D respectively at right-angles to CD, in practice parallel to the edges BC and AD using mesuring instruments in accordance with clause 15. The difference between AD and BC is the deviation from the parallel between AB and CD.

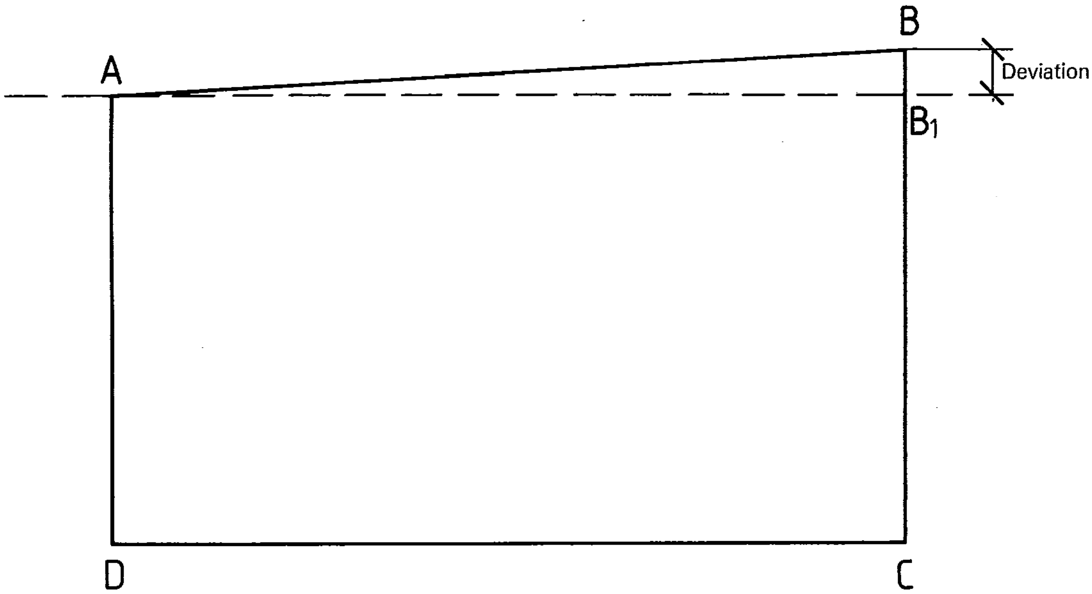


Figure 18

5.3 Accuracy table

Measuring operation	When values for permitted deviation specified for object exceed:	Measuring range	Measuring instrument or tool
1	2	3	4
Angular deviation (5.1)	± 4 mm	< 1,2 m	Square
	± 5 mm/m	< 30 m	Calibrated steel tape
	± 7 mm	< 30 m	Optical instrument
Parallelism (5.2)	± 2 mm	< 1 m	Caliper
	± 3 mm	< 3 m	Calibrated steel tape
	± 5 mm	3 to 10 m	Calibrated steel tape
	± 5 mm	< 3 m	Measuring rod

6 Straightness and camber of components

This clause describes examples of measuring instruments and tools for the determination of deviations from straightness and from designed camber.

6.1 Straightness

According to ISO 4464, straightness deviation is described as the difference between the actual form of a line and a straight line. The deviations a and b are measured as the distance from points on the actual line to the straight line joining the ends of the actual line, A and B. (See figure 19.)

Straightness deviations are determined using instruments and tools given in clause 15, with or without the aid of position pieces.

The ends of the line, commonly an edge, along which the deviation from straightness is to be measured, are linked either using a string stretched between the two end points, A and B, a straight edge supported by position pieces or the sighting axis of a measuring telescope.

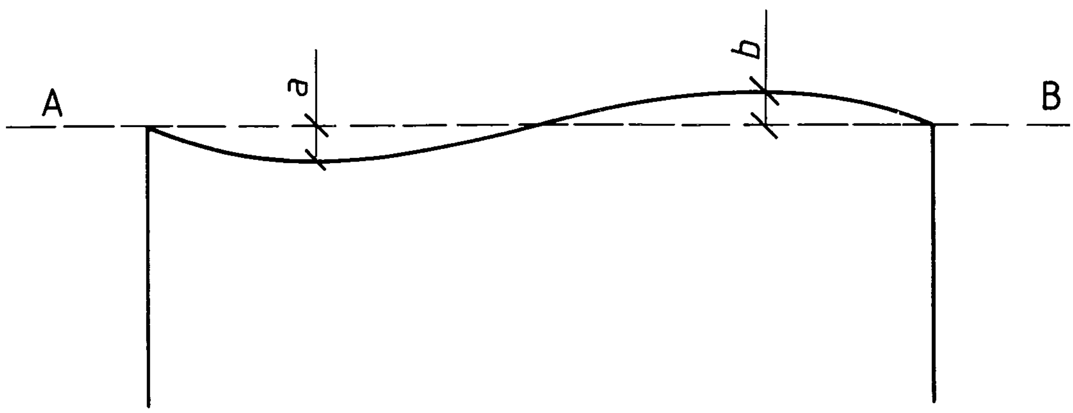


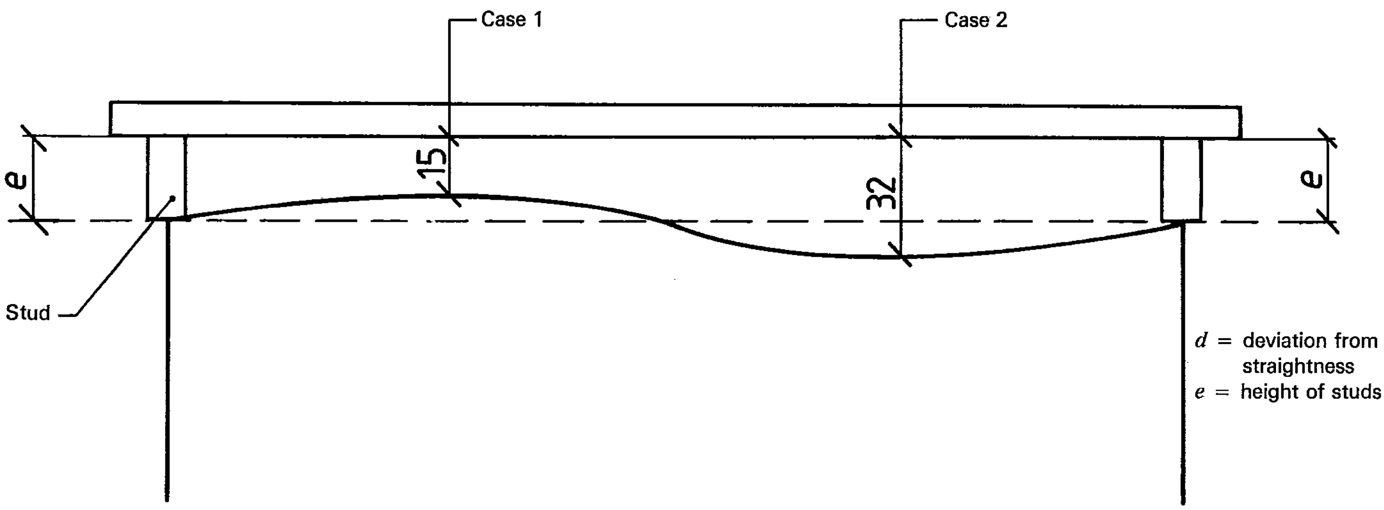
Figure 19

6.1.1 Measuring using a straightedge

The length of the straightedge should not exceed 3 m.

Figure 20 shows measurement using a straightedge and corner pieces along the edge of the object of measurement.

Dimensions in millimetres



Example The deviation is calculated as follows:

e = height of studs: 25 mm
deviation $d = e -$ reading
Case 1: $d = 25 - 15$
d = 10 mm (pos.)

Case 2: $d = 25 - 32$
d = −7 mm (neg.)

Figure 20

6.1.2 Measuring using a stretched wire

The method in figure 21 consists of setting up a reference line with a stretched steel or nylon wire, supported at its ends by distance and tensioning pieces. The wire is kept in place by a groove 50 mm from the edge.

The aim of the distance and tensioning pieces is to keep the wire at a predetermined distance from the corners of the object of measurement and to ensure that it does not touch the surface.

6.1.3 Measuring using a measuring telescope

The methods described in 5.1.3 for a measuring telescope used in the determination of angular deviation can also be used to determine the straightness of components.

6.2 Designed camber

The methods described in 6.1.1 to 6.1.3 can also be used to determine deviations from designed camber.

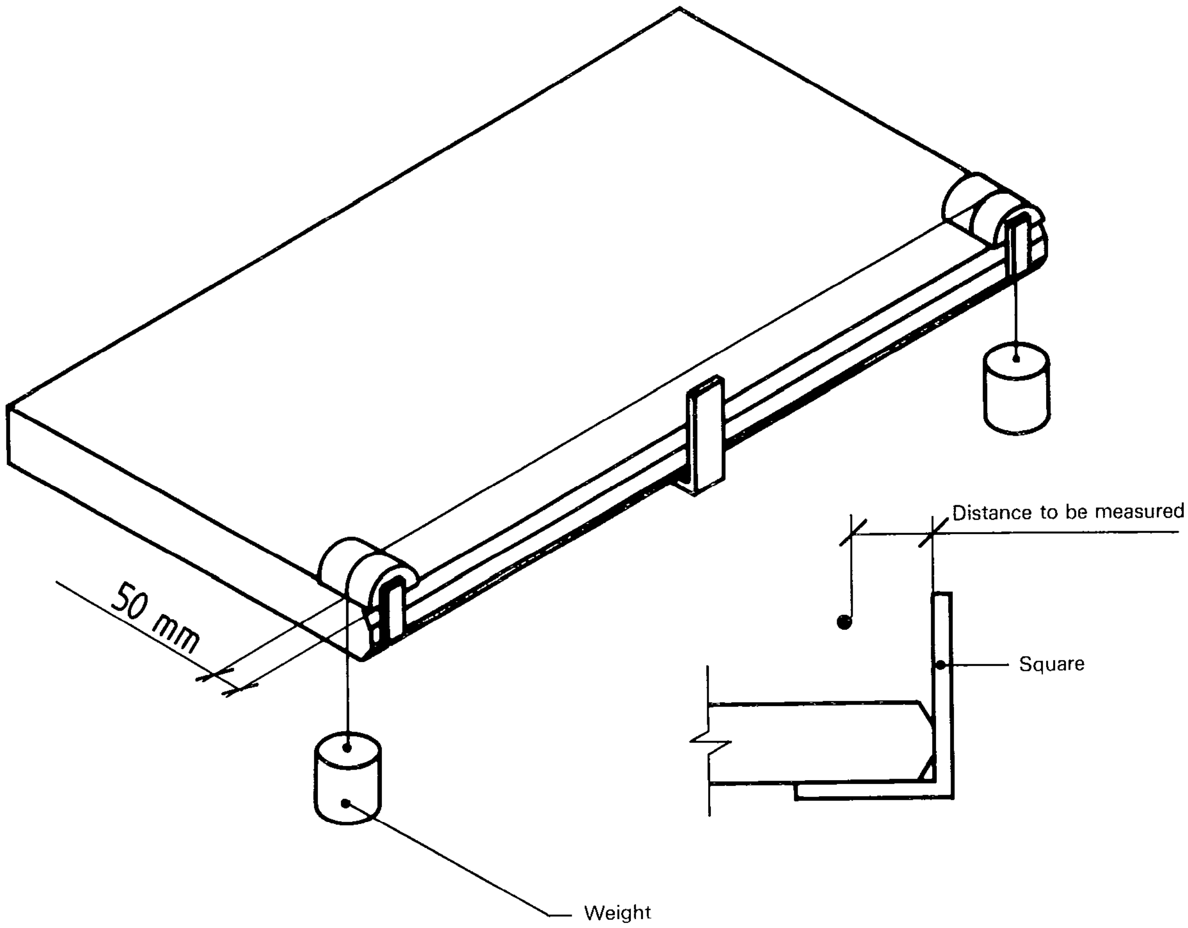


Figure 21

6.3 Accuracy table

Measuring operation	When values for permitted deviation specified for object exceed:	Measuring range (measuring length)	Measuring instrument or tool
1	2	3	4
Deviation from straightness and designed camber (6.1 and 6.2)	± 2 mm	< 3 m	Measuring wedge (< 30 mm), straightedge and corner pieces
	± 3 mm	< 3 m	Rule, straightedge and corner pieces
	± 2 mm ± 4 mm ± 8 mm	< 2 m 2 to 5 m 5 to 10 m	Measuring wedge (30 mm) and steel or nylon wire (< 10 m) and corner pieces
	± 3 mm ± 5 mm ± 10 mm	< 2 m 2 to 5 m 5 to 10 m	Rule and steel or nylon wire and corner pieces

7 Flatness and skewness of components

This clause describes examples of instruments, tools, measuring methods and reference planes to be used for the determination of flatness.

According to ISO 4464, flatness deviation is described as "the difference between the actual form of a surface and that of a plane surface". In the case of local flatness these surfaces are substituted by a line and a straight line respectively. When determining deviations from flatness, it is necessary to decide from which reference plane the deviations of the surface are to be measured.

7.1 Principles of measurement

A reference plane can be defined in many different ways, such as:

- a mean plane of the four corner points;
- a plane determined with the aid of the method of least squares;
- in relation to certain straight lines (local flatness);
- in relation to a box (the box principle);
- a plane through three corner points (skewness).

7.1.1 Mean plane

Flatness deviations on a rectangular surface can, according to ISO 4464, be determined with the help of a mean plane for all four corners. This mean plane will be situated $S/4$ above two diagonally opposite corners and $S/4$ below the other two corners (see figure 22) where S is the degree of skewness determined as shown.

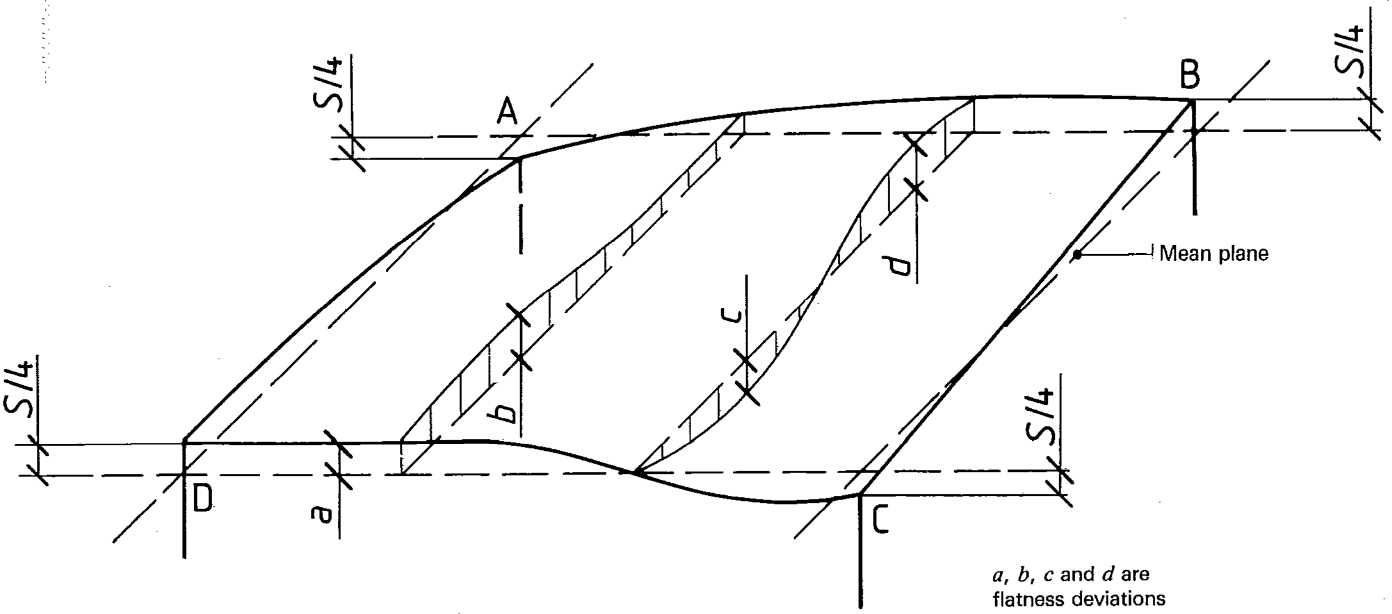


Figure 22

In figure 22, the reference plane is the mean plane passing through A + $S/4$, B − $S/4$, C + $S/4$ and D − $S/4$. The flatness deviations are measured at points all over the surface and not only in sections; the sections in the figure are shown for the sake of simplicity. The surface is scanned in relation to the mean plane. Flatness deviation is expressed positively and negatively by the greatest distance of a point above and below that plane.

7.1.2 Method of least squares

A more general definition of flatness is that the reference plane is so constructed that the sum of the surface deviations from that reference plane is zero; i.e. the sum of the positive deviations equals the sum of the negative deviations, and the sum of the squares of these deviations is a minimum (that is, principle of least squares). For such a plane a large number of measurements is required (approximately 16 points on a component of size 4 000 mm × 6 000 mm), while calculations must be done by computer.

It should be noted that the evaluation when using the method of least squares should be entrusted to well qualified personnel.

NOTE — The application of the principle of least squares implies that the calculation result gives the position and the two directions of the reference plane in relation to the measuring plane. Only in those cases where the surface to be measured is already a part of the erected building can the two directions normally be subject to accuracy requirements.

Figure 23 shows the reference plane to be calculated with the aid of the principle of least squares.

A measure of the quality of the flatness can, by way of example, be specified as:

$$|V\text{ pos.}| + |V\text{ neg.}| \leqslant T_{\text{fl}}\text{ mm}$$

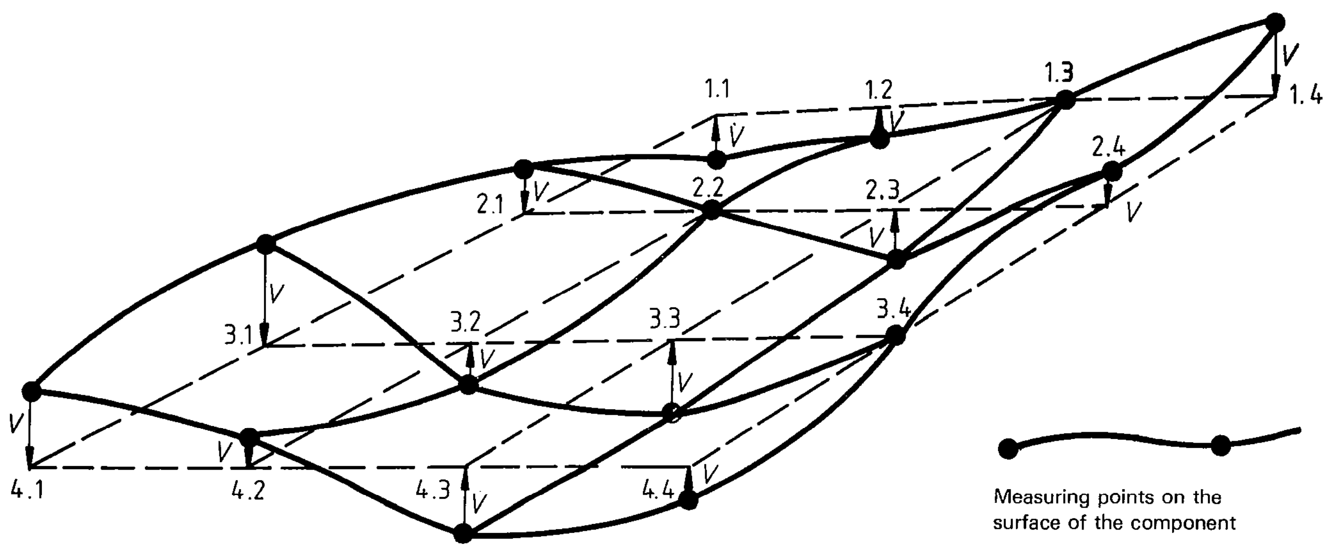
where

- V pos. is the largest positive deviation;
- V neg. is the largest negative deviation;
- T_{fl} is the specified flatness tolerance.

7.1.3 Local flatness

Local flatness deviations from certain straight lines in certain directions can be measured.

This method gives a direct measure of local straightness and indirectly an indication of flatness. It is a practical method of checking flatness for many building purposes.



Conditions: $\sum_i V_i = 0$

$$\sum_i V_i^2 = \text{minimum}$$

(i = 1.1; 1.2; 1.3 ... 4.4)

Figure 23

Figure 24 shows flatness deviations a_1 in relation to a reference plane ABCD or deviations a_2 in relation to a straight reference line through the points X and Y on the surface of the component.

7.1.4 The box principle

The box principle may be used to determine flatness deviations. According to ISO 4464, the box principle is described as follows: "The volume to consider is the volume of the space which exists between two theoretical similar parallelepipeds having the same orientation, one of them being situated inside the other. The distance between the corresponding faces of these parallelepipeds may or may not be equally distributed depending on the tolerance widths which are specified. No point on the surface of the component shall pass beyond this volume."

NOTE — This principle is also applicable when only two dimensions are under consideration. This will probably be the most common situation. (See figure 25.)

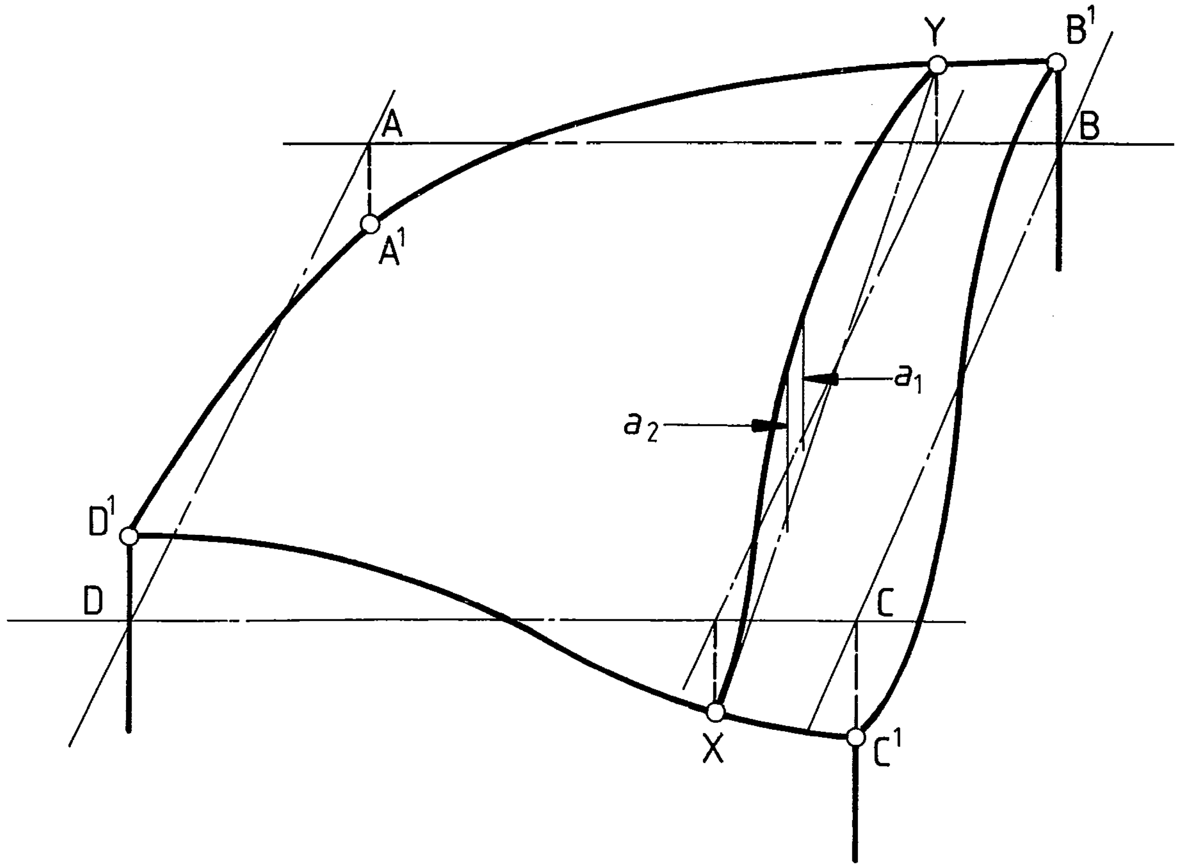


Figure 24

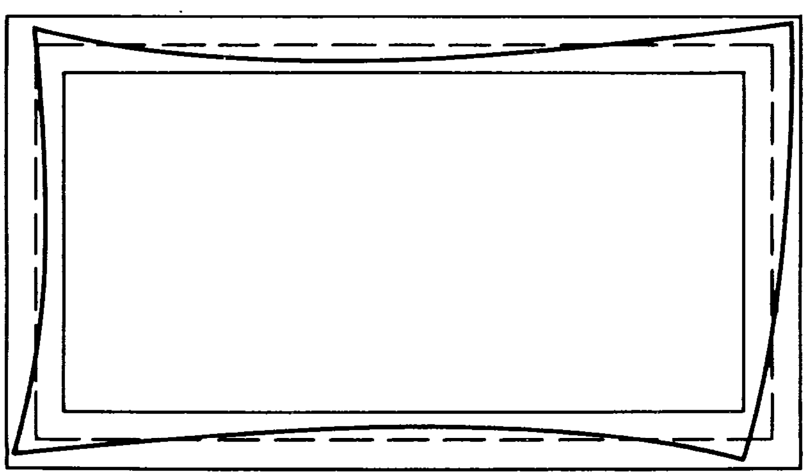


Figure 25

As shown in figure 25, for two-dimensional components such as bars or plates, a simplified box principle may be used.

The general use of the box principle with a three-dimensional rectangular co-ordinate system requires measurements in three planes.

7.1.5 Skewness

According to ISO 4464, skewness is a special case of flatness deviation. This means that a reference plane passing through three corner points of the component to be measured (or rather points near the corners, since corner points are usually difficult to identify) can be chosen. The skewness is then described as the absolute value of the deviation of the fourth corner point from that reference plane. Deviations from the reference plane of any other points on the surface are then regarded as flatness deviations. Due to the skewness, large flatness deviations may thus be observed.

Flatness deviations are determined using the measuring instruments indicated in clause 15, where typical sources of errors and precautions needed are also given.

The methods given below show some of the various possibilities of measuring the general shape of the surface of the component. The specifications should firstly indicate the reference plane to be used and additionally give the permitted deviation. Flatness should generally be related to a specified area of a finished surface, to a single component, to the junction between two components or between two stages in the formation of a "plane" surface. Large areas like floors are usually controlled by tolerances on level and sometimes on skewness in relation to grid points (see clause 9).

7.2 Overall flatness

7.2.1 Measuring flatness deviations with a measuring telescope

Measurements can be made with levelling instruments or theodolites. Combined with the measurement of thickness, these methods give an example of the application of the box principle.

A note to subclause 7.3.3.2 in ISO 4464 : 1980 states: "In practice the measurement is made from a plane exterior to the component and parallel to two main directions of the component."

This recommendation can be fulfilled for such methods as demonstrated in 7.2.2. For other methods, where levelling instruments or theodolites are used, this recommendation cannot be fulfilled. For such cases it is recommended that the instruments are levelled as normal and that the measuring values are transformed in relation to the chosen reference plane. To facilitate the calculations, programmable field computers can be used.

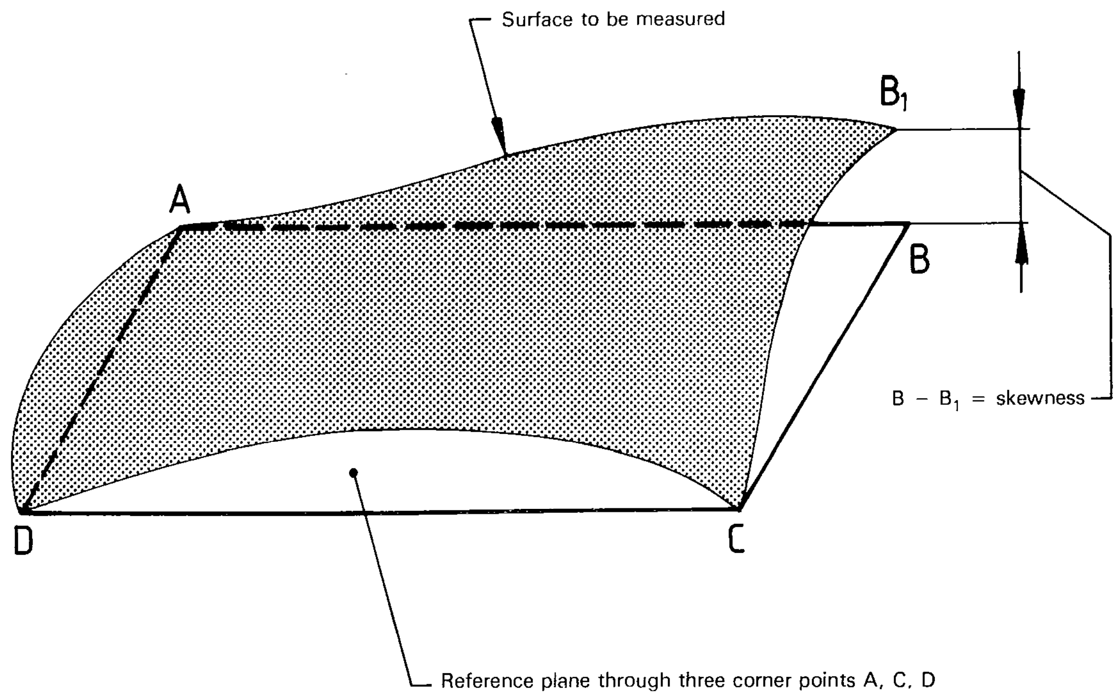


Figure 26

7.2.1.1 Component in vertical position

A vertical plane is swept by a theodolite, a levelling instrument with a 100 gon (90°) prism or surface indicating device (construction laser). The plane should be approximately 300 mm from the surface to be measured. In direct sunshine this shall be increased to at least 500 mm to avoid distortion due to refraction.

The instrument is levelled in the normal manner. The measuring rods or levelling staves shall be placed as nearly as possible perpendicular to the sighting axis of the instrument and as nearly as possible perpendicular to the object being observed.

Figure 27 gives an example of determination of overall flatness deviations.

If a theodolite is used, measurement shall be carried out in both faces. To avoid focussing errors, the minimum focussing distance shall be kept larger than 10 m.

Dimensions in millimetres

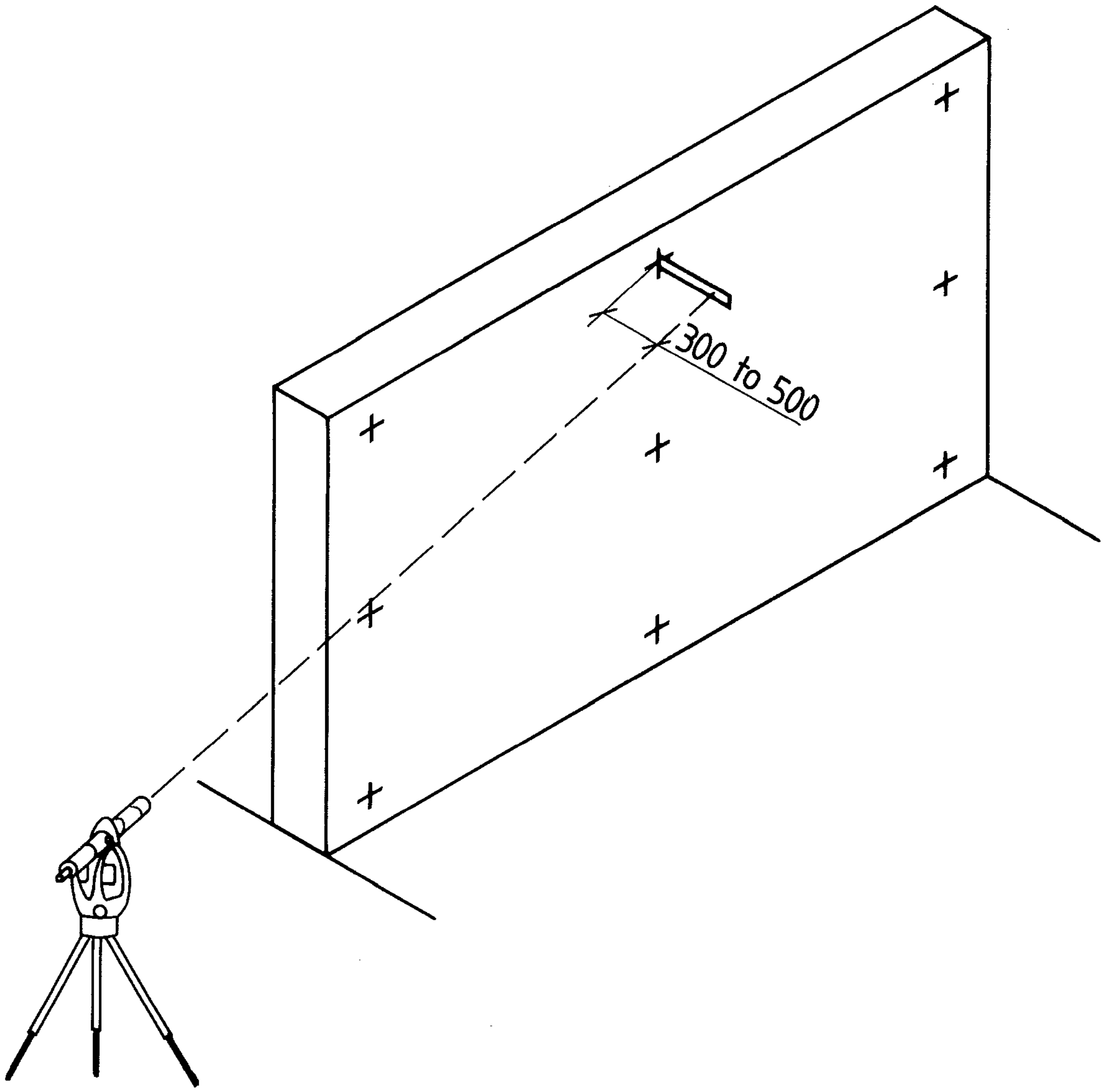


Figure 27

7.2.1.2 Component in horizontal position

The use of a levelling instrument is recommended. An alternative is to use a theodolite the telescope of which is clamped horizontal. Readings are taken on a levelling staff the verticality of which shall be checked with the aid of a bull's eye level.

In figure 28, short levelling staves (300 mm), mounted on a footplate, are available. They have the advantage that only one operator is needed. The disadvantage is that refraction can cause reading errors.

7.2.2 Measuring flatness deviations using specially designed instruments

Two examples of specially designed non-compensator short focussing equipment for the measurement of flatness are given in figures 29 and 30. With these sets of equipment it is easier to follow the recommendation in ISO 4464 about a measuring plane "exterior to the component and parallel to two main directions of the component", than when using levels or theodolites placed at some distance from the component. The equipment described in figures 29 and 30 has the advantage that it can be used for the measurement of components in any attitude.

The examples given in figures 29 and 30 have a plane passing through three corners of the component as reference plane. When choosing the mean plane as a reference plane, the measuring values shall be transformed to this mean plane.

Figure 29 gives an example of measuring flatness in relation to a reference plane through three corner points (B, C and D). (In some cases the instrument at C is provided with a fixed right-angle, which permits direct reading of right-angle deviations at the target B.)

NOTE — It has to be remembered that instruments should be investigated for possible focussing errors.

It is not permitted to use compensator instruments since this method can be used in any plane, and not the horizontal plane only.

The sighting axis of the measuring telescope at point C (figure 29) is orientated towards the zero points on the scales at B and D. These zero points correspond with the height of the sighting axis above the surface at point C.

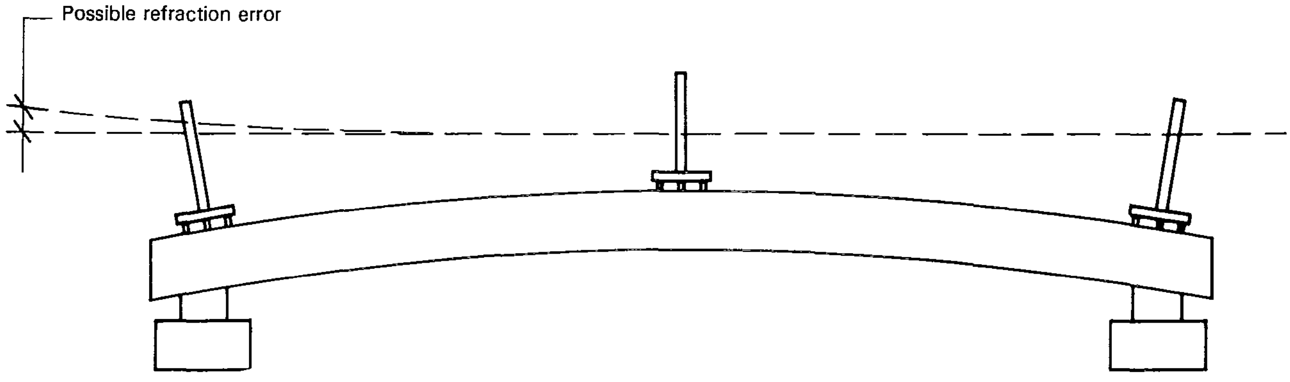


Figure 28

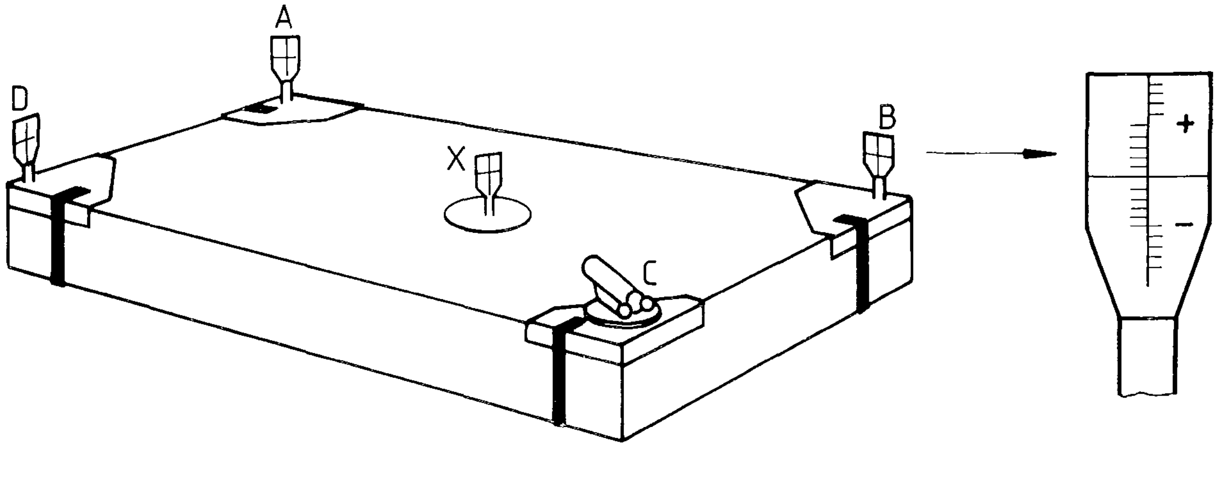


Figure 29

Readings are then made to the target X which can be placed at any arbitrary point on the surface. (Reading at point A gives the skewness, see 7.4.) The same measuring principle can be applied with the equipment given in figure 30, which consists of a surface indicating device (D) and a measuring unit (M), detector or telescope, which is centred in the reference plane defined by the unit D.

Measuring flatness of opposite surfaces (with the instrument in two positions, right side up and upside down) combined with thickness is an example of the application of the box principle.

7.3 Local flatness

The methods given do not give the flatness deviations from a certain reference plane but only deviations from one or more straight reference lines, each of which passes through at least two points on the surface of the object of measurement. Measuring thus implies the use of sections.

For this simplified method the following items shall be noted in the inspection schedule:

- in which direction and on which side of the surface the sections are to be chosen;
- how many sections and how many points per section are to be reported;
- how results are to be reported;
- any other item of importance.

In the following examples, only three points are used — two reference points and one point which is to be measured.

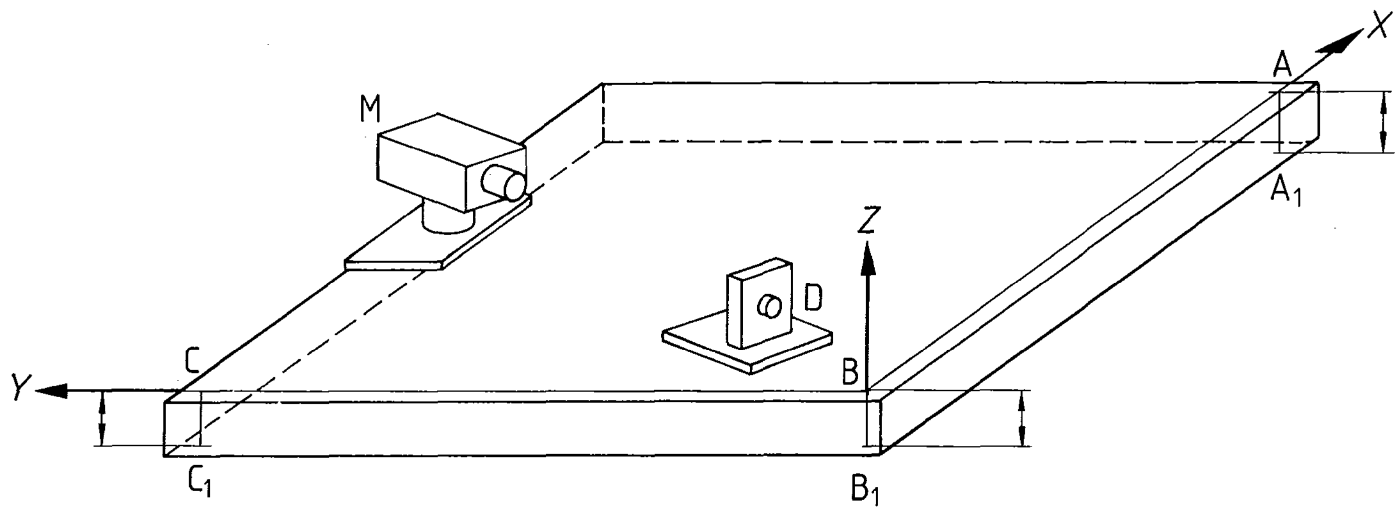


Figure 30

7.3.1 Measuring local flatness using a wire or straightedge

A straightedge (with or without a spirit-level) or a wire can be used for measuring components in a horizontal, vertical or inclined position. (See figure 31.) Using a spirit-level, the measurement can be combined with a verticality check. The tools are placed on fillets of equal and known thickness Y. The measurement X between the surface and the wire or straightedge is made with a rule or a measuring wedge. Care should be taken that the wedge does not lift the wire. The straightness deviation is $(X - Y)$, and this is an indication of flatness.

Wires shall be stretched with a force of 100 N.

It must be observed that when measuring with a wire suspended in the horizontal position, the measuring range is limited to about 10 m. An 0,5 mm diameter high-tensile steel wire should be used.

Measuring straightness deviations with the aid of a wire should be avoided during rain and strong wind.

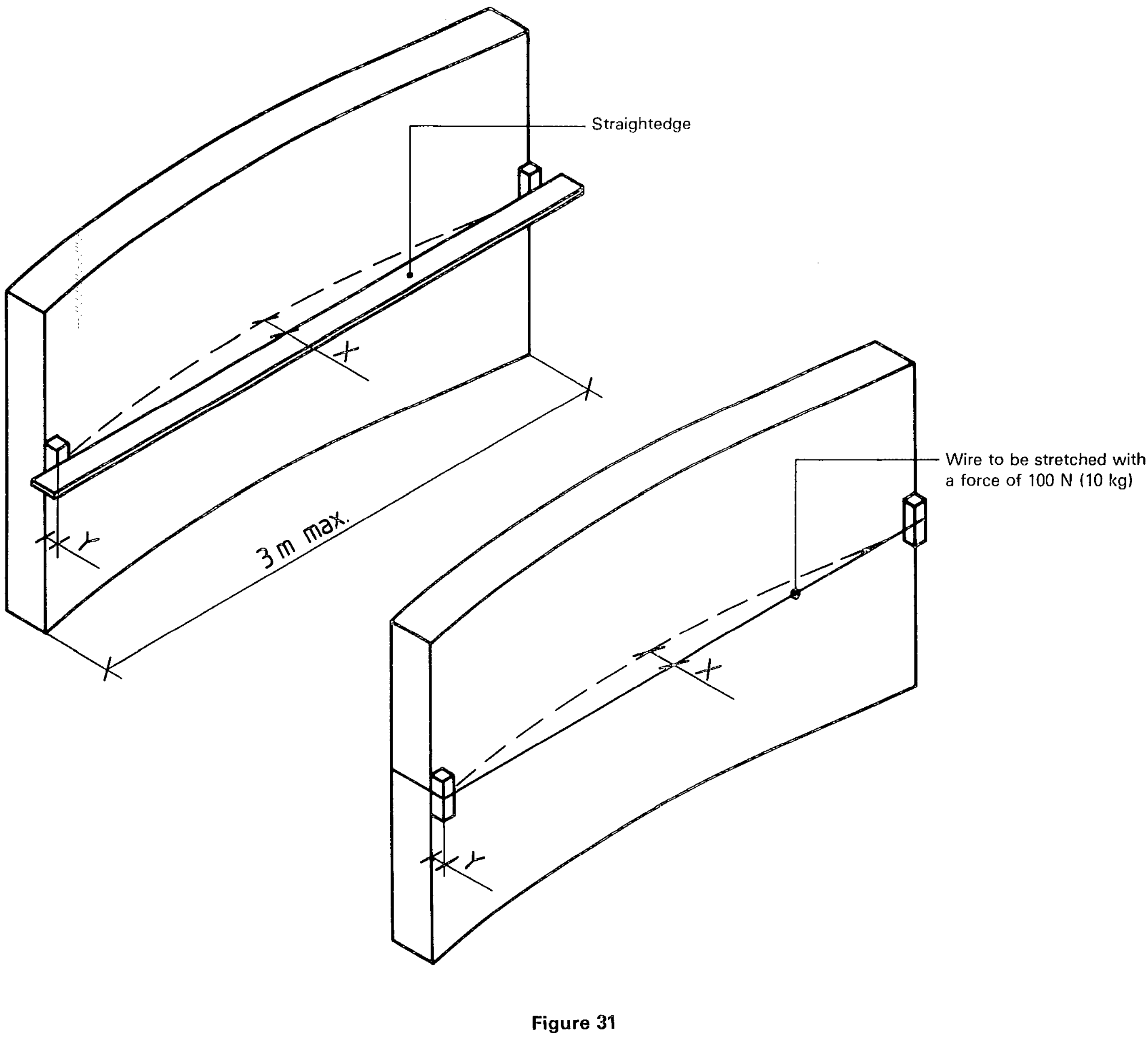


Figure 31

7.3.2 Measuring local flatness with a measuring telescope

7.3.2.1 Component in vertical position

A vertical plane is swept by a theodolite, levelling instrument with a 100 gon (90°) prism or a surface indicating device (construction laser). The plane should be approximately 300 mm from the surface to be measured. In direct sunshine this distance shall be increased to at least 500 mm to avoid distortion due to refraction.

The instrument is levelled in the normal manner.

The measuring rods or levelling staves shall be placed as nearly as possible perpendicular to the sighting axis of the instrument and as nearly as possible perpendicular to the object being measured.

Figure 32 gives an example of the measuring of local flatness. The local flatness deviation, d, is

$$d = \frac{R_1 + R_3}{2} - R_2$$

where R_1, R_2 and R_3 are the readings on levelling staff placed in the positions R_1, R_2 and R_3, respectively.

If the component is not quite vertical, this shall be allowed for if deviations are measured at points other than the centre.

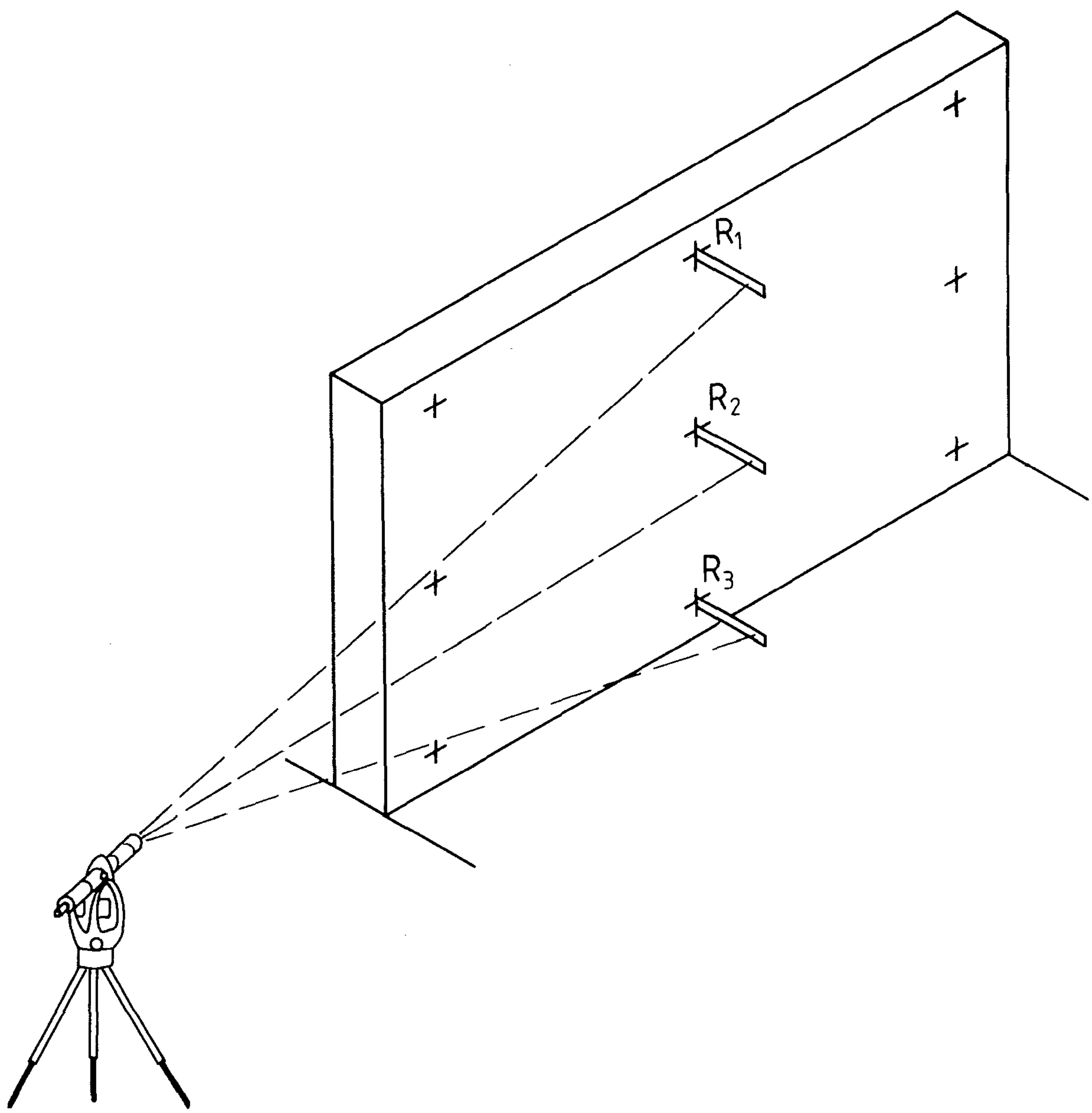


Figure 32

7.3.2.2 Component in horizontal position

The use of a levelling instrument is recommended. An alternative is to use a theodolite the telescope of which is clamped in the horizontal position. Readings are taken on a levelling staff the verticality of which shall be checked with the aid of a bull's eye level.

Figure 33 gives an example of the measuring of local flatness. The local flatness deviation, d, is

$$d = \frac{R_1 + R_3}{2} - R_2$$

where R_1, R_2 and R_3 are the readings on levelling staff placed in the positions R_1, R_2 and R_3, respectively.

If the component is not quite horizontal, this shall be allowed for if deviations are measured at points other than the centre.

7.4 Skewness

7.4.1 Measuring skewness using a wire or straightedge

Either a straightedge or a stretched high-tensile steel wire is placed between two diagonally opposite corner points on the object to be measured. The distance from the surface of the object to the straightedge or wire is then measured for the first diagonal, giving d_1, and then the other, giving d_2, measurement being taken at the centre of the surface, i.e. the point of intersection of the diagonals. The degree of skewness of the surface, a, is

$$a = 2(d_1 - d_2)$$

Figure 34 shows measuring skewness with the aid of a wire and a measuring wedge. Care should be taken that the wire is not lifted by the wedge.

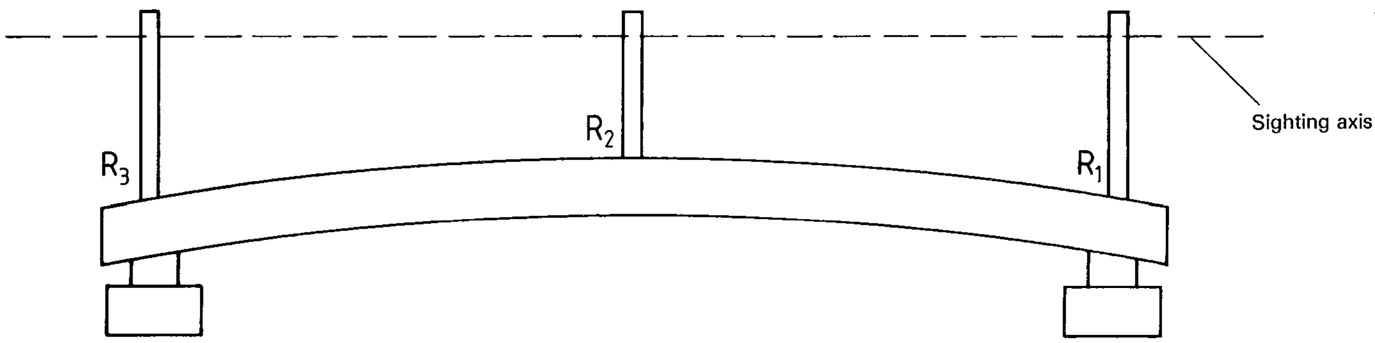


Figure 33

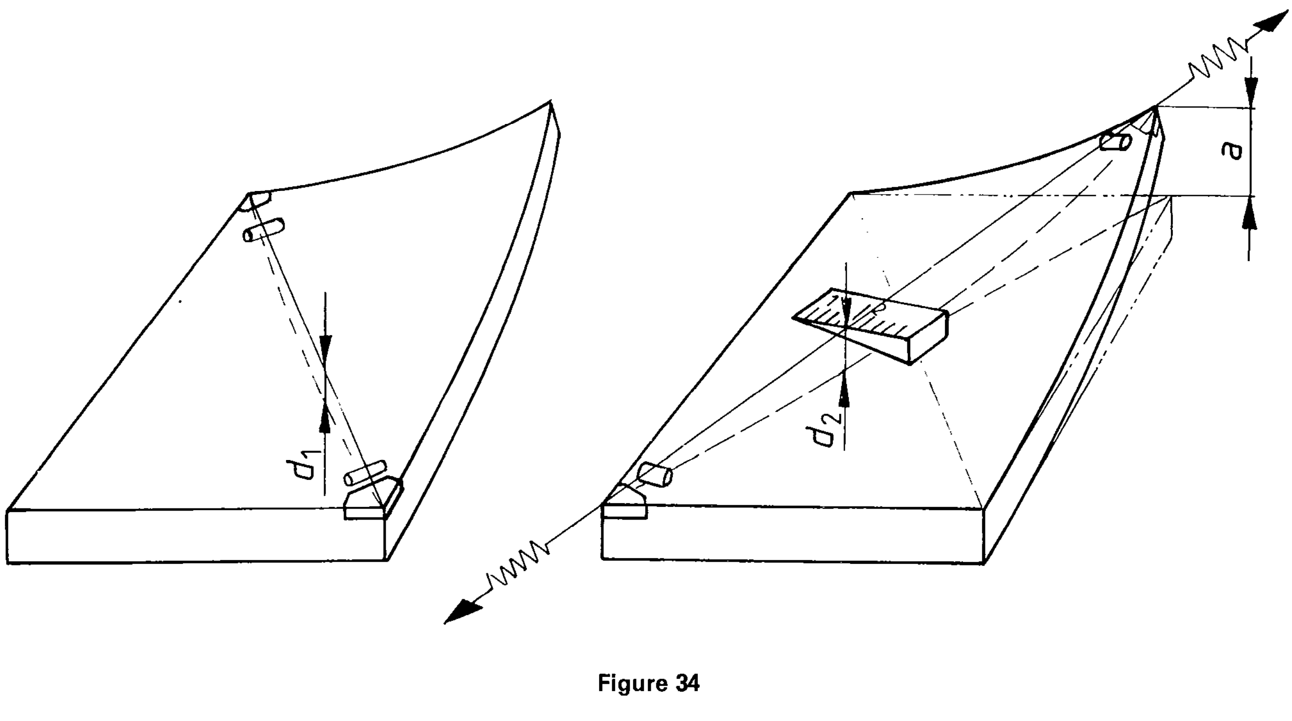


Figure 34

Wires shall be stretched with a force of 100 N. When measuring with a wire suspended in the horizontal position, the measuring range shall be limited to about 10 m. An 0,5 mm diameter high-tensile steel wire should be used. Measuring straightness deviations with the aid of a wire should be avoided during rain and strong wind.

7.4.2 Measuring skewness using a measuring telescope

See also 7.2.1 and 7.3.2.

The distances from the plane of the sighting axis to the four corners are measured and a plane which intersects any three of the corner points is calculated. The distance of the fourth corner from this plane is calculated, thus giving the skewness deviation (figure 35). A parallel plate micrometer may be attached to the telescope when higher accuracy is required. The skewness at R_4, a_4, is

$$a_4 = (R_1 + R_3) - (R_2 + R_4)$$

where R_1, R_2, R_3 and R_4 are the readings on measuring rod or levelling staff placed in the positions R_1, R_2, R_3 and R_4, respectively.

7.5 Methods and equipment when measuring components according to the box principle

Measuring according to the box principle can, with some difficulty, be carried out using normal equipment and methods, that is surveying instruments, tapes, large squares and tensioned strings, but since much calculation work is needed to combine these deviations into the acceptance criteria of the box principle, it is seldom performed. However, quite often a partial box principle, on 1, 2 or 3 sides of an object is used with standard measuring equipment.

The measuring and calculation work is simplified in most of the systems developed especially for check-measuring concrete components, two of which are shown in figures 29 and 30. These systems are very efficient for use with the simplified box principle.

Stationary measuring jigs can be developed for measurement according to the box principle in direct connection with a production line. They consist of a steel structure in which the object of measurement is supported on three points. Several measuring points are mounted in well defined positions on all sides of the jig on the surface of an imaginary parallelepiped. The distances from the measuring points to the surface of the object of measurement are measured by (for instance) telescopic rods. Control measuring with jigs is extremely fast but for any jig the range of sizes and types of objects to be measured is limited.

The equipment shown in figures 36 and 37 is only an example of equipment used for measurement according to the box principle.

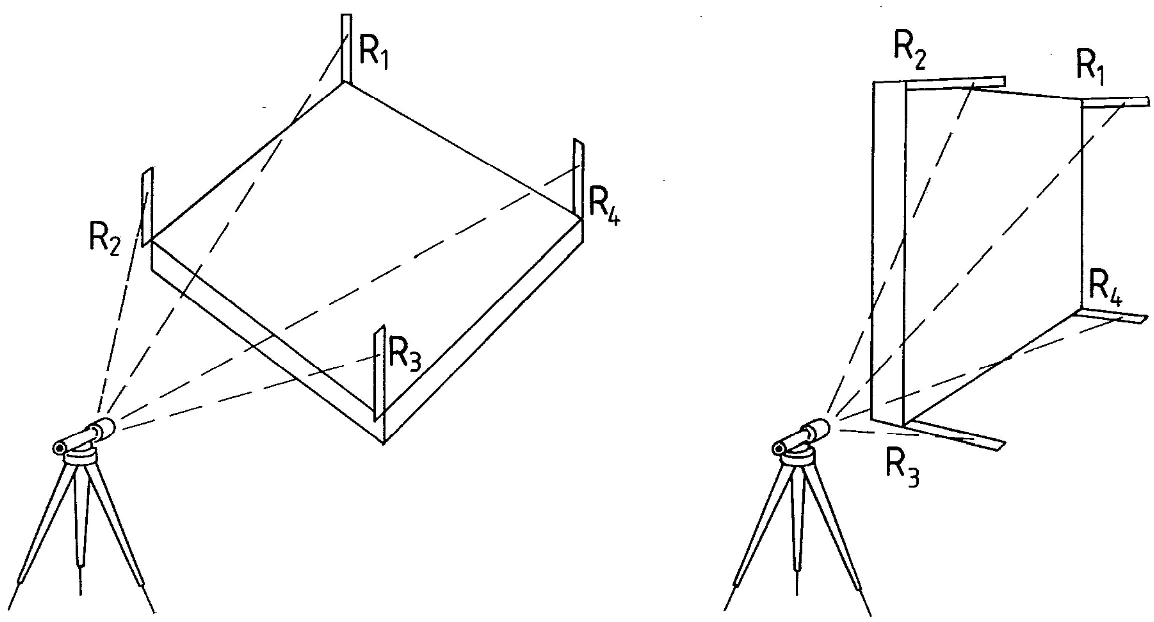
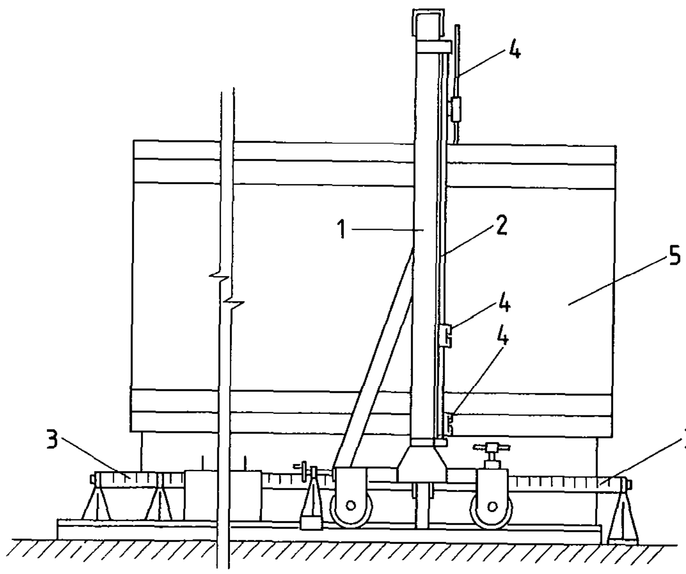
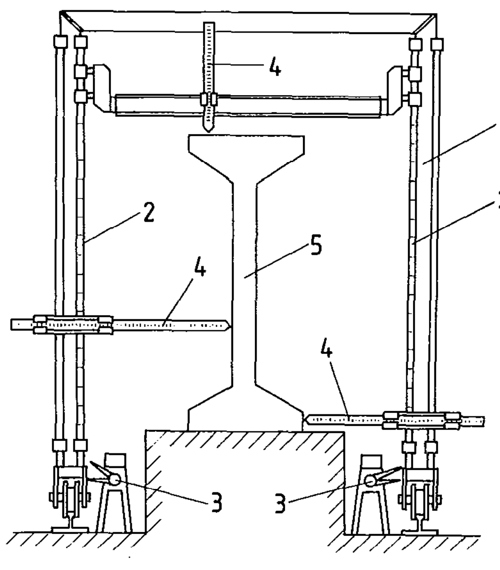


Figure 35

Two examples of measuring equipment on the box principle for the measurement of the overall size of components are shown in figures 36 and 37.



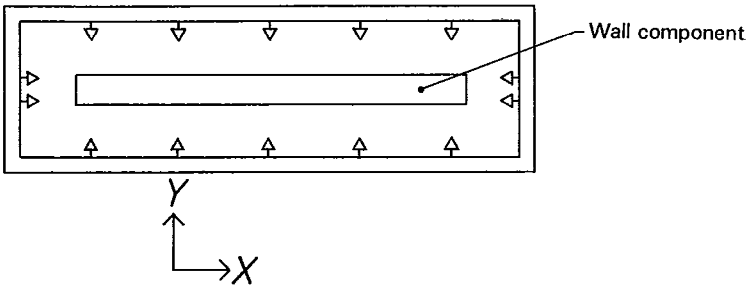
a) **Measuring bench: elevation**



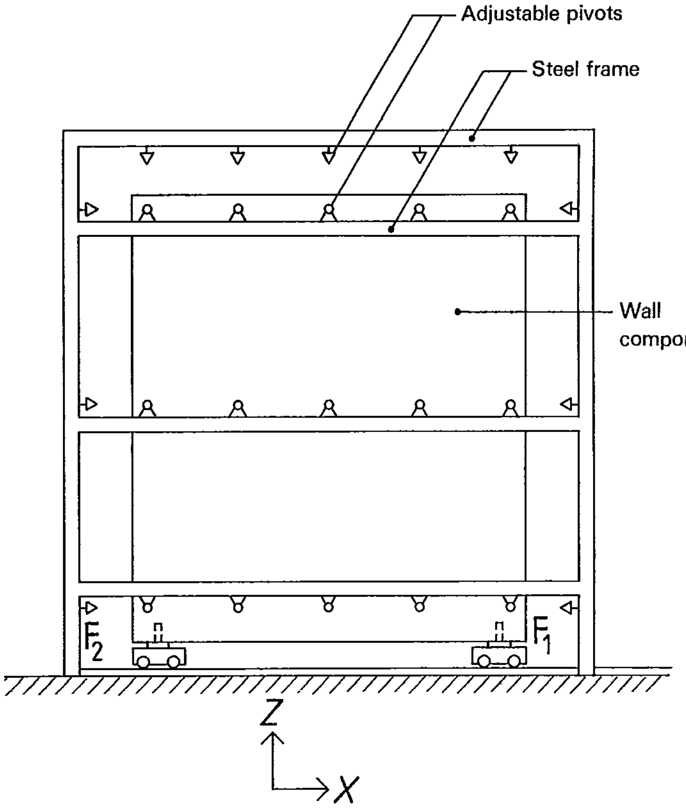
b) **Measuring bench: cross-section**

1: Movable frame
2: Graduated vertical guide
3: Graduated horizontal guide
4: Measuring rod
5: Object to be measured

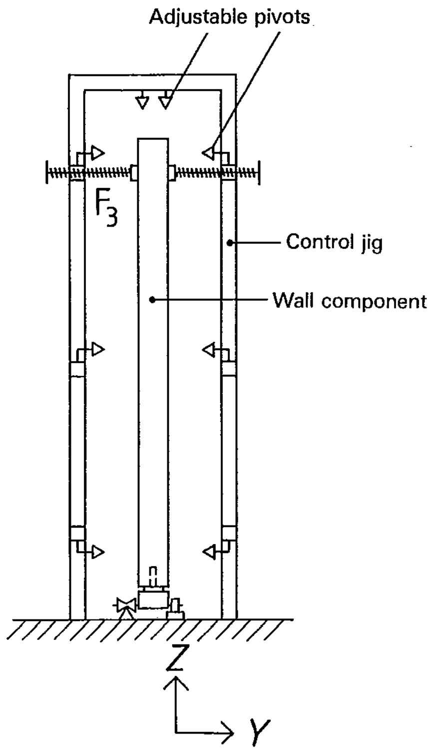
Figure 36



a) Plan



b) Elevation



c) Cross-section

The element is fixed as follows:

At F_1 in the X-, Y- and Z-direction

At F_2 in the Y- and Z-direction

At F_3 in the Y-direction

Figure 37

7.6 Accuracy table

Measuring operation	When values for permitted deviation specified for object exceed:	Measuring range (measuring length)	Measuring instrument or tool
1	2	3	4
Determination of flatness (7.2, 7.3)	± 2 mm	< 3 m	Straightedge and wedge (30 mm)
	± 3 mm	< 3 m	Straightedge and rule
	± 2 mm ± 4 mm	< 2 m 2 to 5 m	Wire (< 10 m) and wedge (30 mm)
	± 2 mm	< 3 m × 6 m	Levelling instrument or theodolite and staff with parallel plate micrometer
	± 4 mm	< 3 m × 6 m	Levelling instrument or theodolite and staff
	± 3 mm ± 5 mm	< 2 m 2 to 5 m	Wire (< 10 m) and rule or retractable steel tape
Determination of skewness (7.4)	± 4 mm	< 3 m × 6 m	Theodolite or levelling instrument
	± 5 mm	< 3 m × 6 m	Wire (< 10 m) and measuring wedge (30 mm)
Box principle (7.5)	± 3 mm	10 to 200 mm between frame and component	Steel frame and measuring gauges or rules

Section two : Measuring methods for those measurements which can be carried out on building sites only

This section deals with the determination of construction deviations of prefabricated or *in situ* construction.

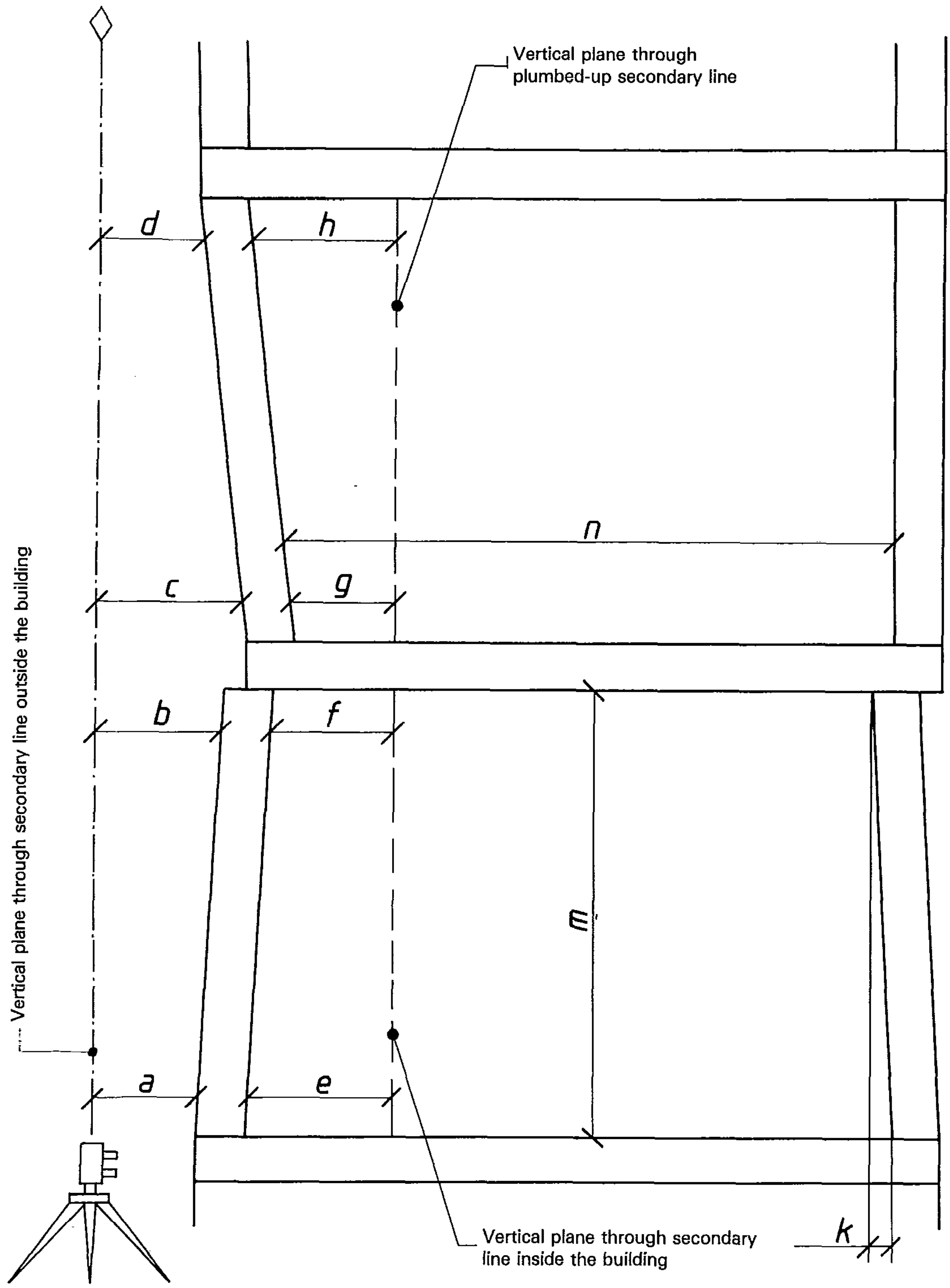


Figure 38

The deviations usually concern the following (see figure 38):

— Clause 8: Positions in the horizontal plane, for instance a, b, c, d for façade or e, f, g, h inside the building;

— Clause 9: Positions in the vertical plane (levelling) (not shown on figure 38);

— Clause 10: Verticality, for instance

k or

b — a or

d — c or

h — g or

f — e;

— Clause 11: Eccentricity, for instance c — b;

— Clause 12: Position in relation to other components, for instance m and n;

— Clause 13: Flatness or straightness Fl_i (see figure 76);

— Clause 14: Other important sizes:

bearing lengths: (see figure 77)

joint widths

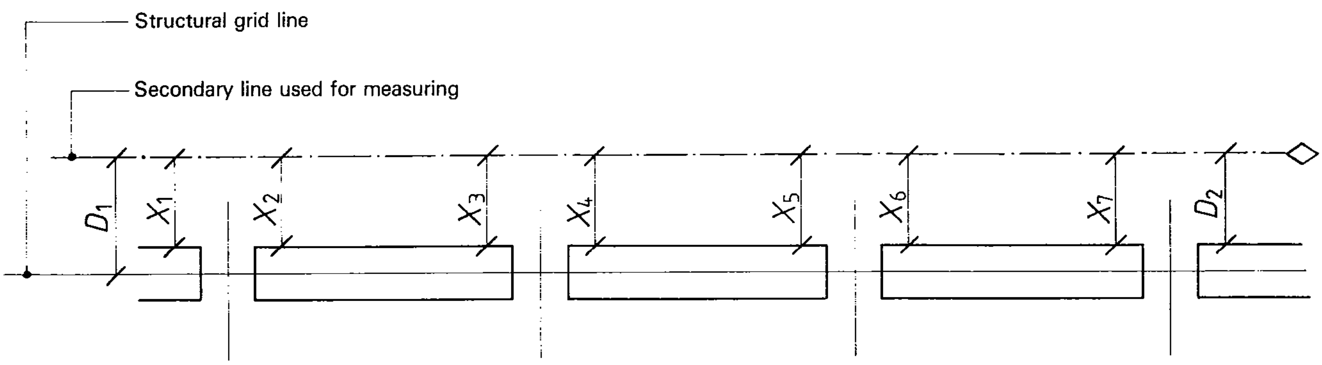
joint steps (see figure 78).

Figure 38 gives examples of some deviations, for instance verticality (clause 10) or eccentricity (clause 11) which can be derived from positional deviations measured from vertical reference planes through secondary lines, outside or inside the building.

Construction measurements are determined using measuring instruments and tools, with or without the aid of position pieces, as shown in clause 15. The typical sources of errors and precautions needed are also covered, for instance tension and temperature when measuring with tapes. To avoid focussing errors in measuring telescopes, it is recommended that the minimum focussing distance is not less than 10 m. If this is not possible the instrument shall be checked for focussing errors. The use of chalk lines is not recommended. The thickness of such lines can vary along their length. The use of chalk lines is therefore limited to assembly only and not for compliance or data collection measurements.

The methods described below are, in general, an application of the offset method in relation to secondary lines. Other survey methods can be used provided that *a priori* accuracy calculations have been carried out. For both compliance measurements and for the collection of accuracy data, the measurement procedure should be significantly more accurate than the permitted deviation specified for the accuracy of the manufacturing or construction process to be measured. This document also assumes the presence of suitable reference positions, according to ISO 4464, on the site of the assembly or in the assembly itself from which measurements can be made, for instance secondary points or grids or bench marks. Structural grid lines, centre lines or other lines used in design are usually not suitable as a direct reference line for measuring since they are seldom visible after the construction of the building part (see figure 39), with the exception of the measurement of positions of bolts prior to the erection of components.

Figure 39 shows how any lines used for the purpose of measurement and intentionally marked parallel to the proposed building or structural grid lines are defined as secondary lines. Before carrying out any of the methods indicated below, the accuracy of secondary lines must be known or be investigated.



D_1, D_2 = known distances

X_1, X_2, etc. = distances to be measured

Figure 39

Figure 40 gives some examples of transferring secondary systems to higher floors:

a) with optical plummet;

b) by the free station point method;

c) plumbing up with theodolite;

d) plumbing up with theodolite and constrained centring.

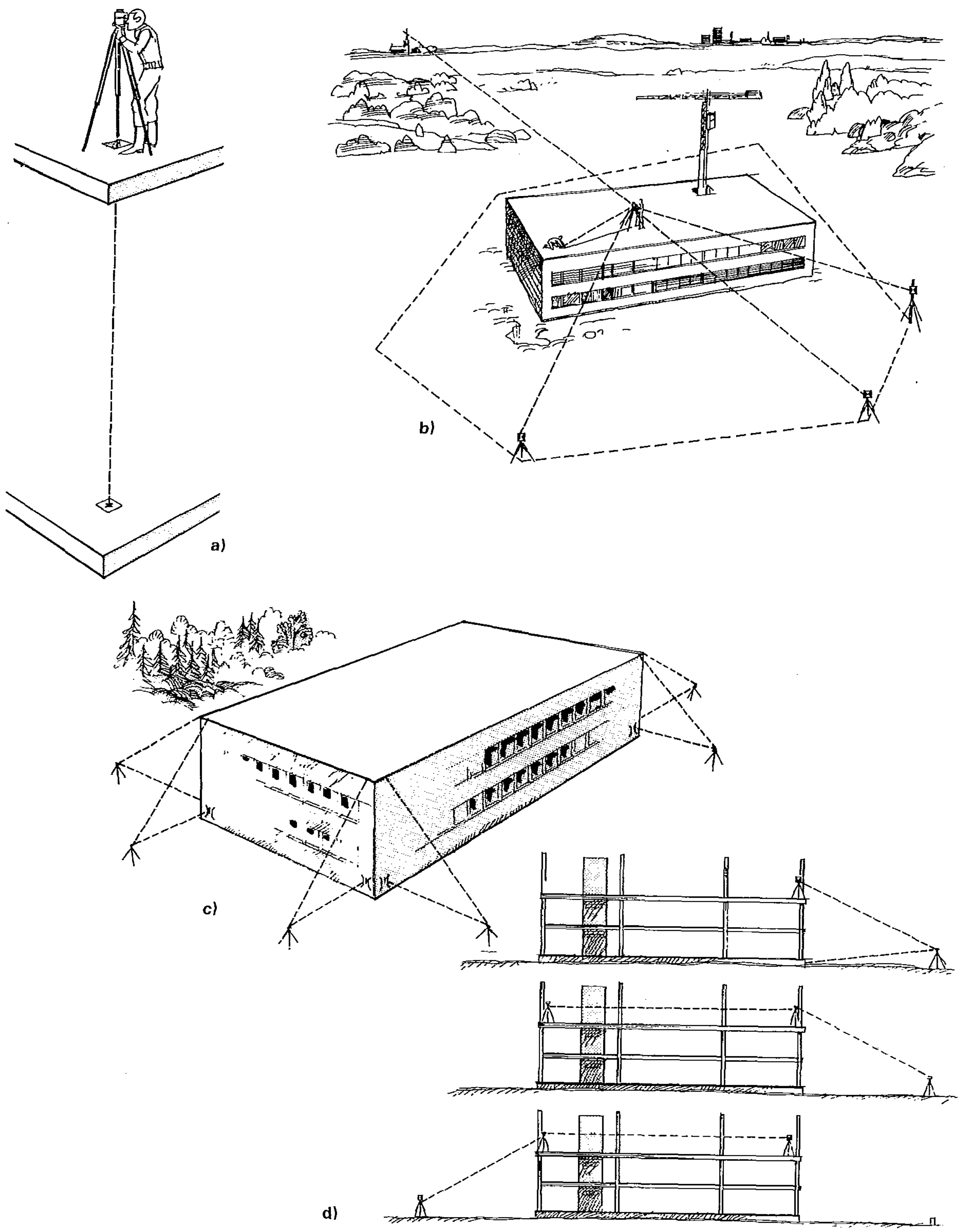


Figure 40

Figure 41 gives examples of two methods of transferring levels.

Levels transferred to a higher floor shall always be checked by levelling back to the original bench mark. (For accuracy requirements, see ISO 4463.)

Measurements shall be planned in such a way that construction deviations measured on different floors can be related to the same reference position such as secondary lines and levels.

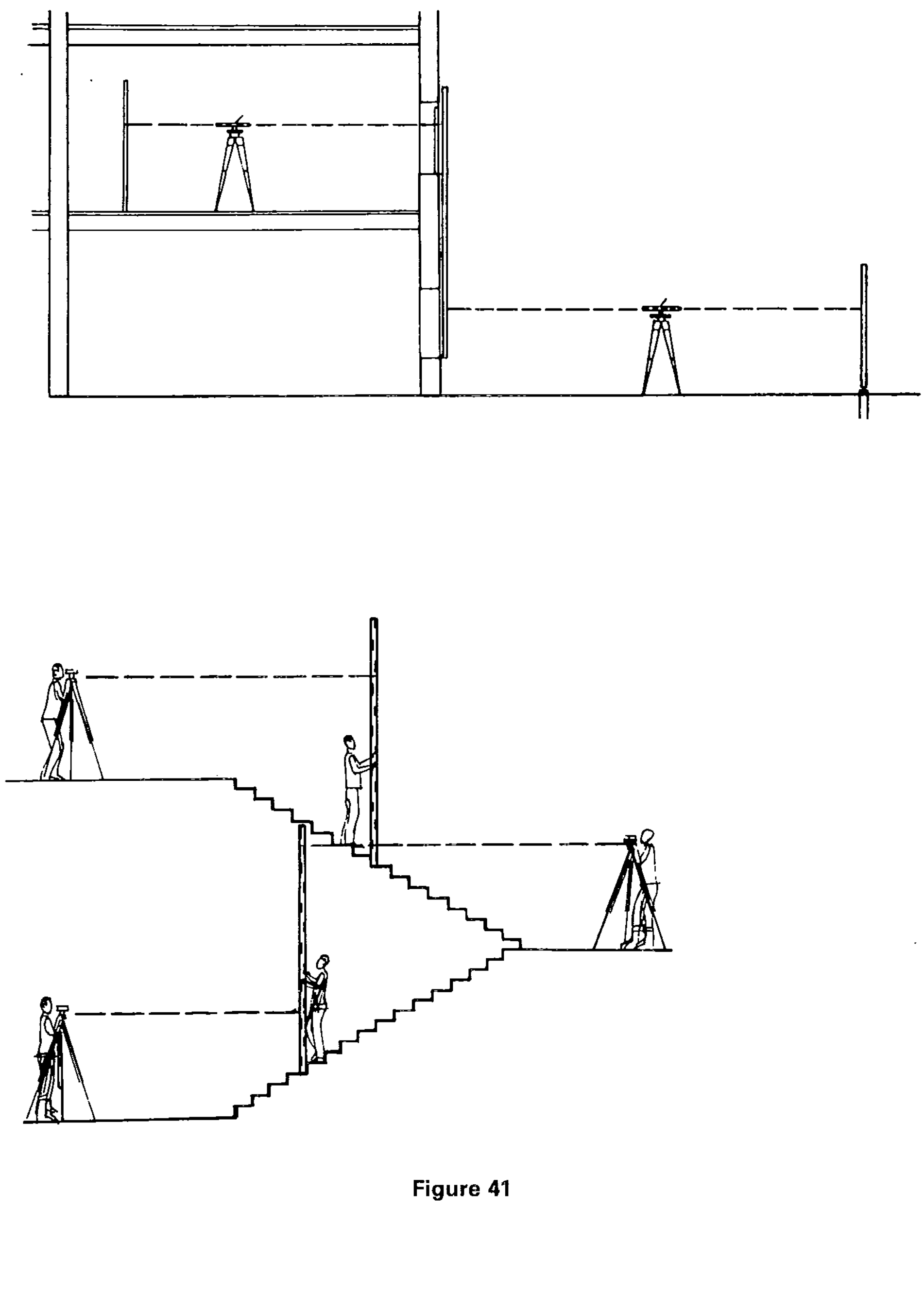


Figure 41

8 Position in the horizontal plane

The measuring procedures given below describe generally the measurement of horizontal distances for the determination of positional deviations, from the combination of which orientation deviations can be calculated, for example deviation from verticality.

8.1 Deviations in relation to structural grid lines

The position of bolts, groups of bolts or guides in pockets for columns can be measured directly from previously marked centre lines used during construction, from secondary lines parallel to the centre lines of these building parts (using a similar method, as described in 8.2) or by the method of free station and the like, depending on the situation on the site.

Some possibilities of measuring the position in relation to a centre line and internal positions are illustrated in figures 42 and 43.

The use of a sheet of metal or other material, in which holes have been drilled representing the internal position of bolts, is not recommended for compliance measurements or when collecting accuracy data. The use of such devices should be restricted to construction work when placing the bolts in their right internal position.

As shown in figure 42, the position of bolts in relation to centre lines or their internal position can be determined with the aid of a theodolite and a measuring tape, a rod or levelling staff. Distance L should not be larger than 30 m, and in any case not exceed the length of the tape, rod or staff. The use of a levelling staff can have the advantage that the measuring team can be reduced from three men (shown in the figure) to two or even one, as the staff has only to be placed in the right position and no tension is needed as for tapes.

To allow millimetre readings or estimations on the tape, rod or staff, the distance D should to be restricted to 40 m. For distances exceeding 40 m, intermediate instrument stations or suitable aiming targets — in accordance with clause 15 — are needed.

This is also valid when measuring from secondary lines parallel to centre-lines.

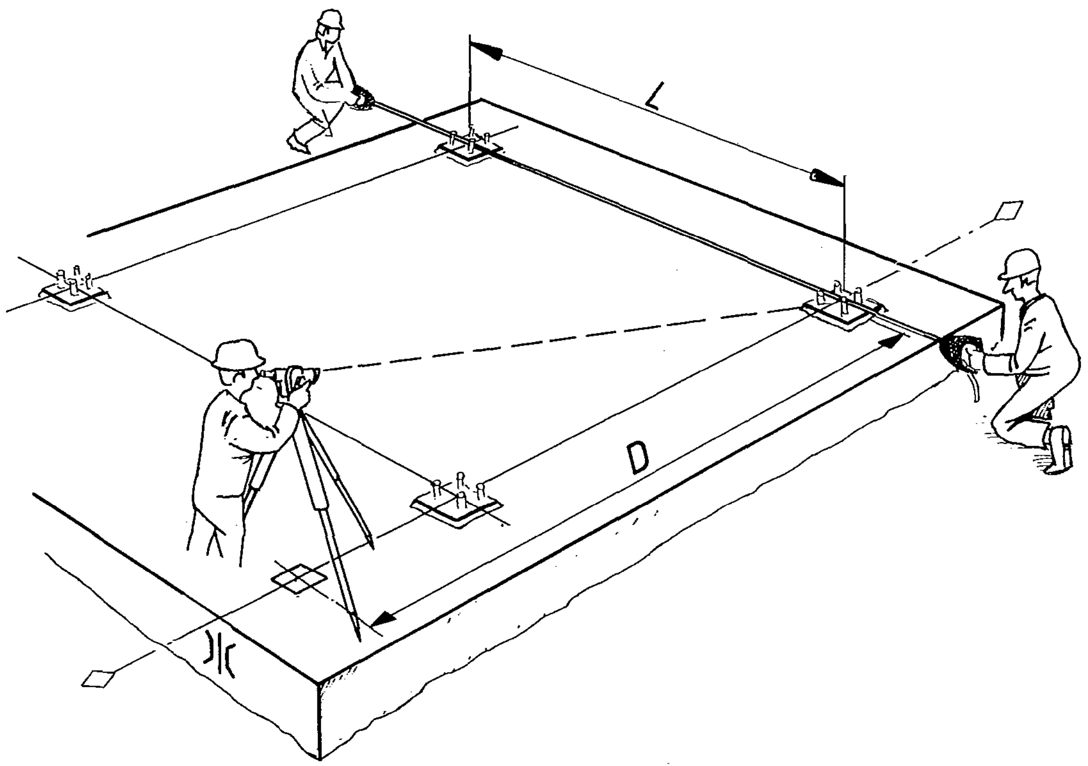
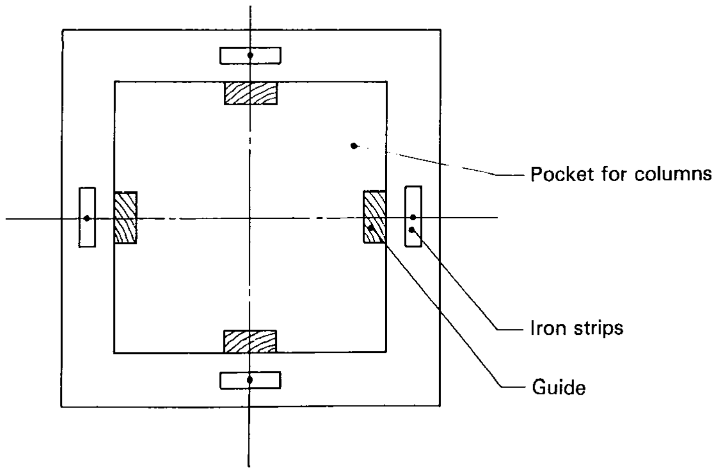
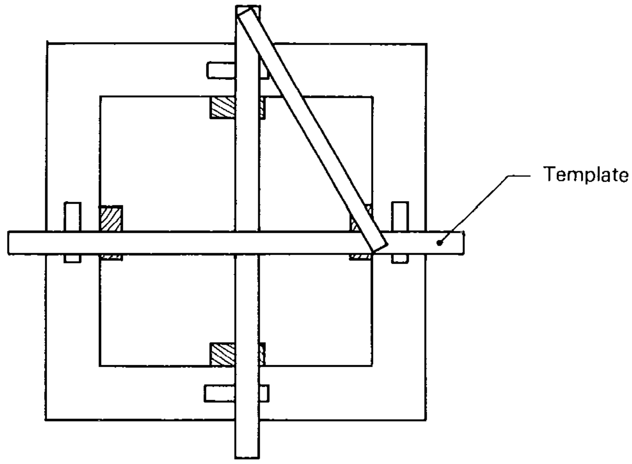


Figure 42

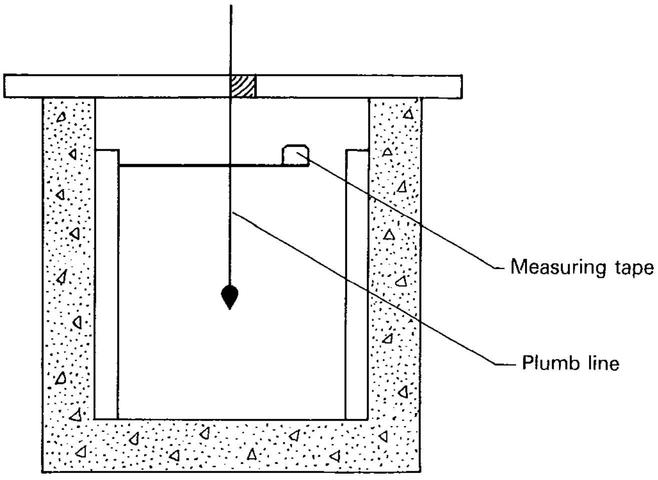
Figure 43 shows an example of the determination of the position of guide pieces for columns.



a) Centre-lines marked on iron strips



b) Determination of point of intersection of centre lines with the aid of a template



c) Fastening a plumbline at the point of intersection and measuring distances from it to the four guides

NOTE — Alternatively, an optical plummet can be used.

Figure 43

8.2 Deviations in relation to secondary lines parallel to the building

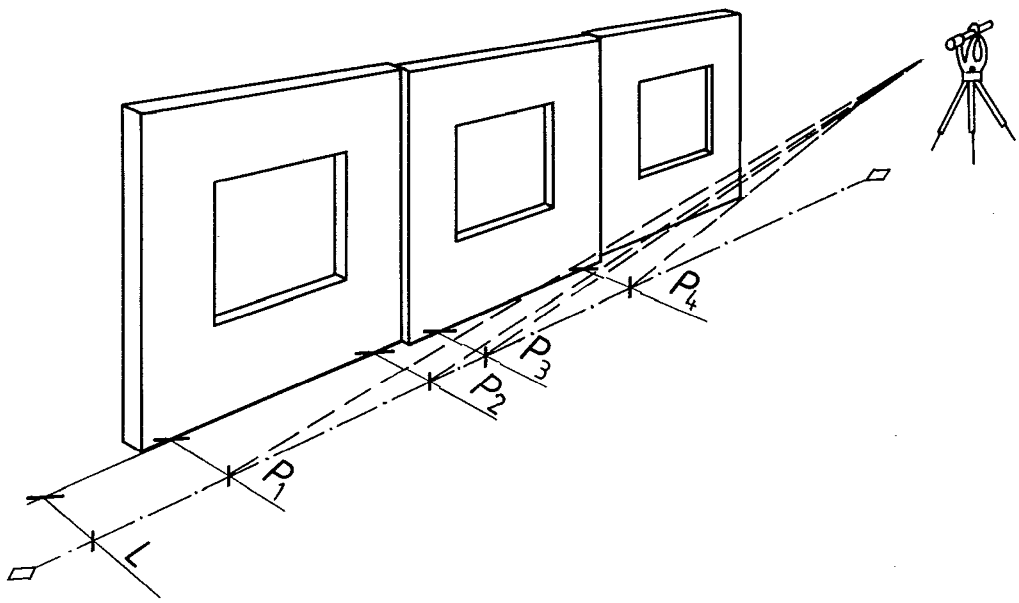
The secondary line should be established by the optical axis of a measuring telescope.

As shown in figure 44, position deviations can be measured at floor level from secondary lines parallel to constructional lines using the offset method. The distance should be measured twice — in face left and in face right.

Positions can also be measured above floor or ground level. Theodolites shall to be used for this kind of measurement. They should be provided with a spirit level with a sensitivity better than 60″.

A vertical plane is swept by the theodolite. The plane should be approximately 300 mm from the surface to be measured. In direct sunshine this shall be increased to at least 500 mm to avoid distortion due to refraction. Measuring long or tall buildings in direct sunshine should be avoided.

The instrument is levelled in the normal manner. The measuring rods or levelling staves shall be placed as nearly as possible perpendicular to the sighting axis of the instrument and as nearly as possible perpendicular to the object being observed.



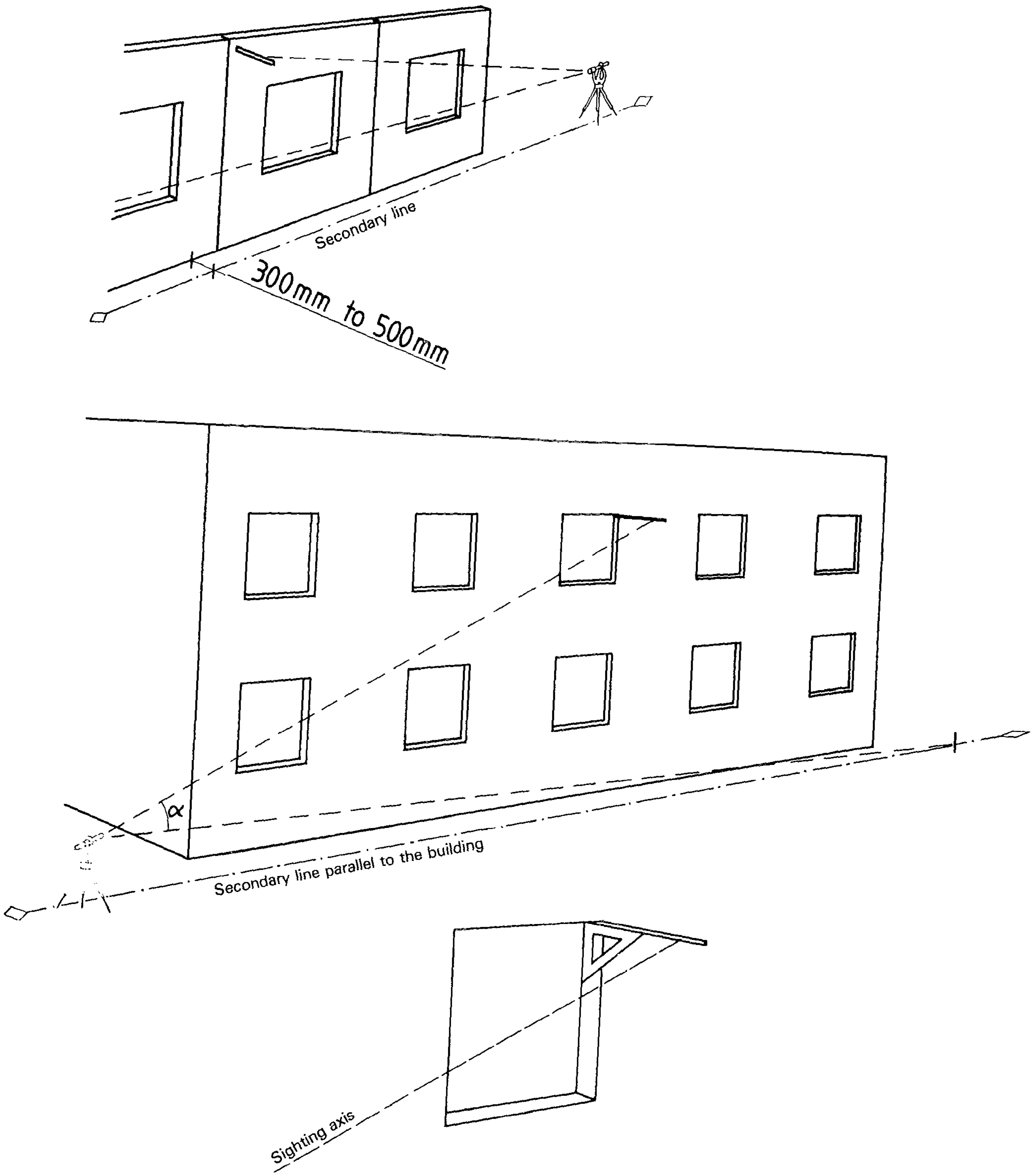
L = known distance

P_1 to P_4 = position in relation to secondary line

$P_2 - P_1$ = orientation deviation according to ISO 4464

Figure 44

Figure 45 shows measuring position deviations from inside or outside the building at higher levels. It is important to check the measurement by measuring in two faces and at right angles to the façade.



Measuring rod with square to ensure that the rod is at right angles to the survey line

Figure 45

8.3 Deviations in relation to secondary lines perpendicular to the building

The determination of position deviations in relation to structural grid lines perpendicular to the building can be carried out with the aid of a measuring tape, always starting from one reference line and closing at the next one as a check. Figure 46 shows the principle.

When measuring position deviations of components in relation to two structural grid lines start at A and close always at B as a check. (See figure 46.)

The result of the measurement from A to B can be checked by starting at B and closing at A.

Some parallax can arise when the side surfaces of components with bevelled edges are projected on the measuring tape. (See figure 47.)

When the joint is too narrow to allow the use of corner pieces, the parallax in the reading of the tape can be avoided by placing a ruler or the flat side of a square against the end surface of the component and perpendicular to the measuring tape.

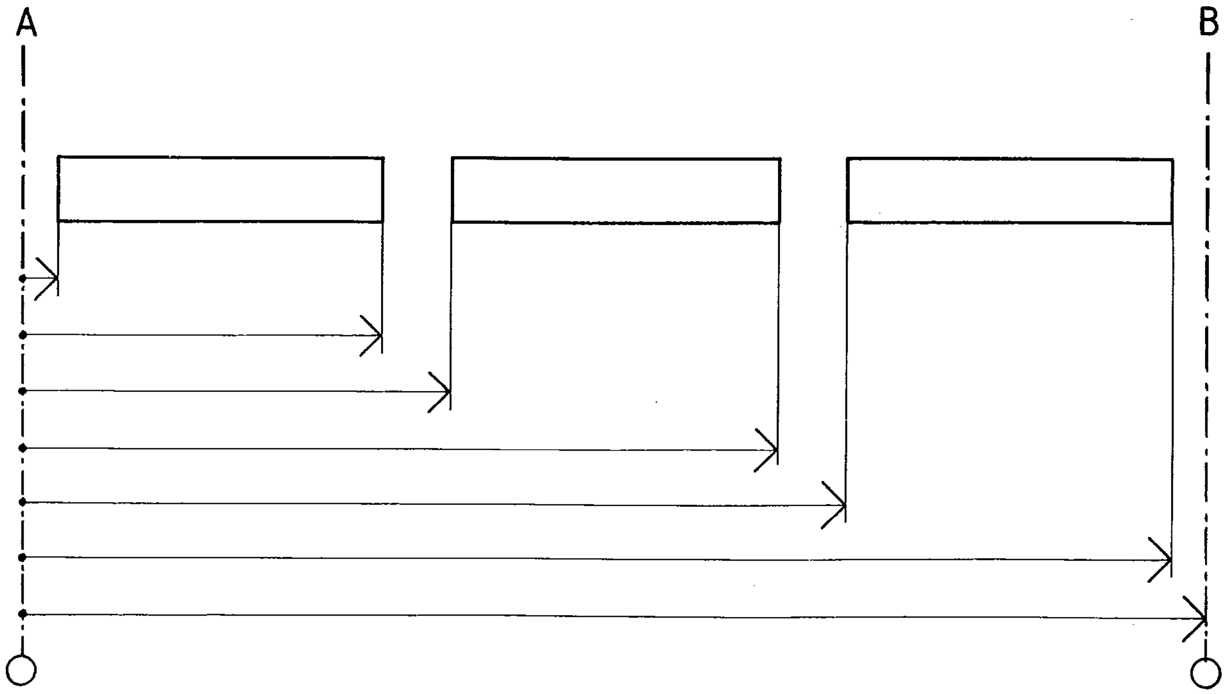


Figure 46

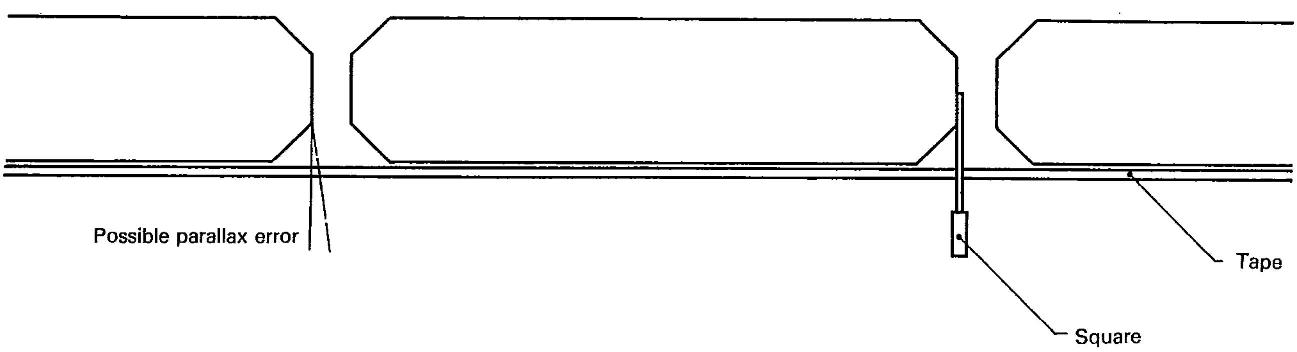


Figure 47

An example of vertical measuring planes through secondary lines on ground level for the measurement of position of walls is given in figure 48.

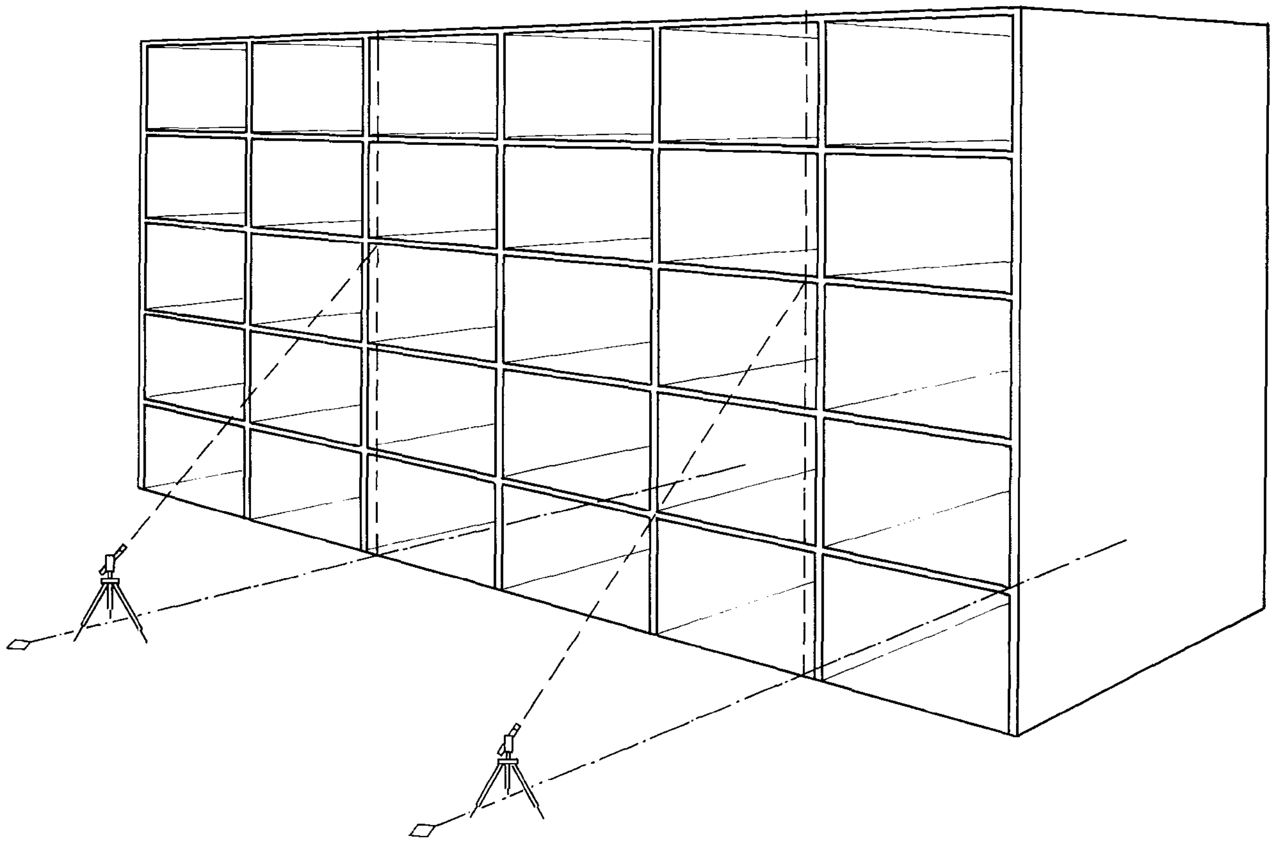


Figure 48

8.4 Accuracy table

Measuring operation	When values for permitted deviation specified for object exceed:	Measuring range[1]	Measuring instrument or tool
1	2	3	4
Position deviations in the horizontal plane:			
from structural grid lines (8.1)	± 5 mm ± 10 mm ± 15 mm ± 20 mm	< 10 m 10 to 20 m 20 to 30 m 30 to 50 m	Theodolite and rod or retractable steel tape
from secondary lines parallel to building (8.2)	± 5 mm	< 40 m provided α < 50 gon	Theodolite and rod (< 1 m)
from secondary lines perpendicular to building (8.3)	± 5 mm ± 10 mm ± 15 mm ± 20 mm	< 10 m 10 to 20 m 20 to 30 m 30 to 50 m	Calibrated steel tape
	± 5 mm ± 10 mm ± 15 mm ± 20 mm	< 10 m 10 to 20 m 20 to 30 m 30 to 50 m	Calibrated steel tape and square
	± 5 mm ± 10 mm ± 15 mm ± 20 mm	< 10 m 10 to 20 m 20 to 30 m 30 to 50 m	Theodolite, measuring rod and calibrated steel tape

1) α = angle of elevation

9 Deviations from level (levelling)

Floors and ceilings are usually levelled at points defined by a grid. The inspection schedule indicates the spacing of the grid.

Figure 49 gives examples of levelling of floors (B) and ceilings (C) on grid points. It is recommended to have at least two bench marks (A) on each floor.

Readings should normally be taken in millimetres. Staves shall be held vertical with the aid of a bull's eye level. Measurement surfaces shall be clean. After completing all measurements the sight axis shall be checked by taking a second reading at the reference bench mark. If the reading differs from the first reading at the bench mark, then all measurements taken from that instrument station shall be checked.

The distance between the instrument and the staff should not exceed 40 m.

The measuring result can be used for the determination of both the levels and the flatness deviations of floors and ceilings.

NOTES

1 Since sighting distances are usually unequal, the levelling instrument should be checked for collimation error.

2 More detailed treatment of measurement procedures for the determination of flatness of floors where extremely small permitted deviations are specified will be the subject of a future International Standard.

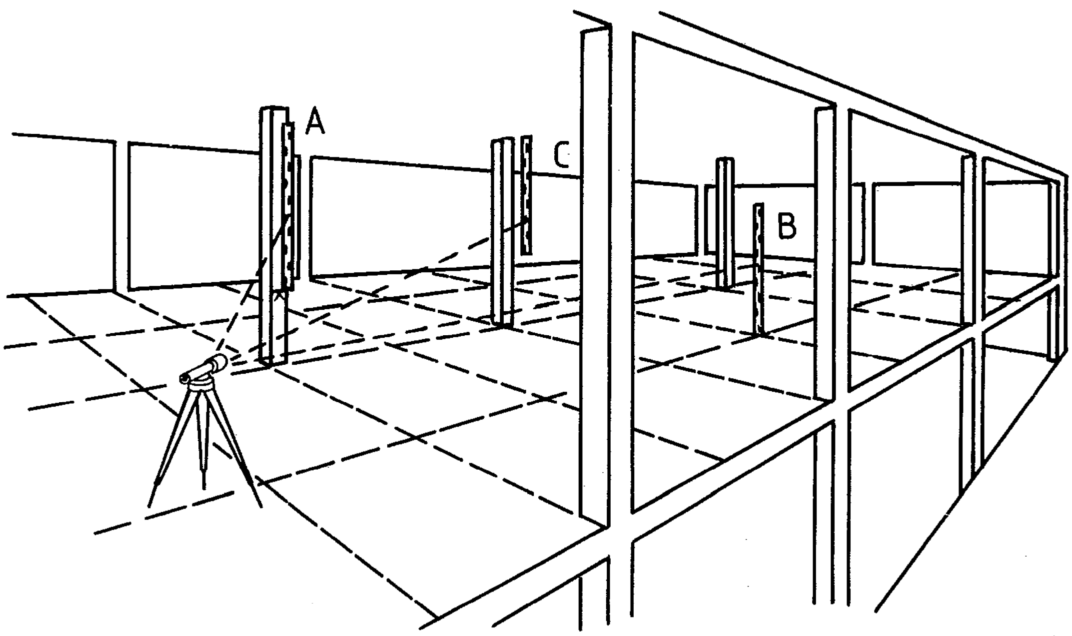


Figure 49

For the transfer of levels, see figures 41 and 73.

In figure 50, the level of the top of the unit is checked by suspending a levelling staff on it. Check first the deviations from verticality *before levelling.*

In figure 51, for the levelling of the top of beams, corbels or panels from below it can in some cases be necessary to provide the leg of the levelling staff with a position piece.

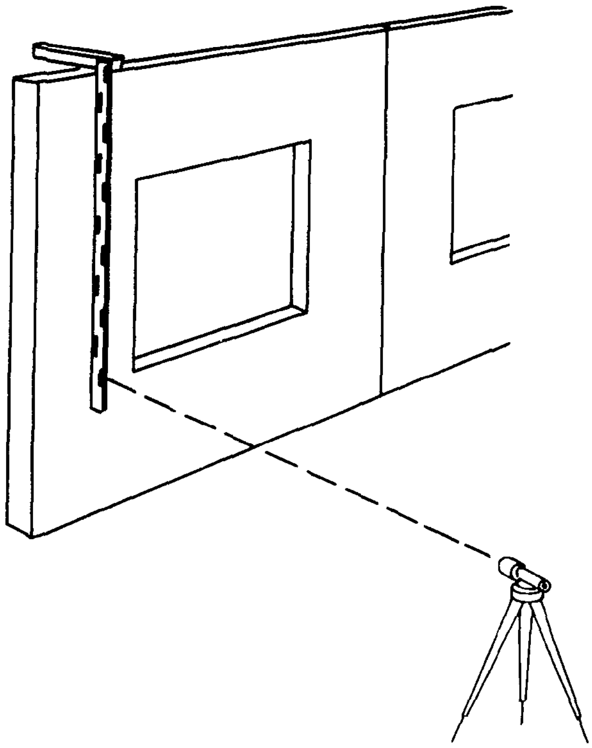


Figure 51

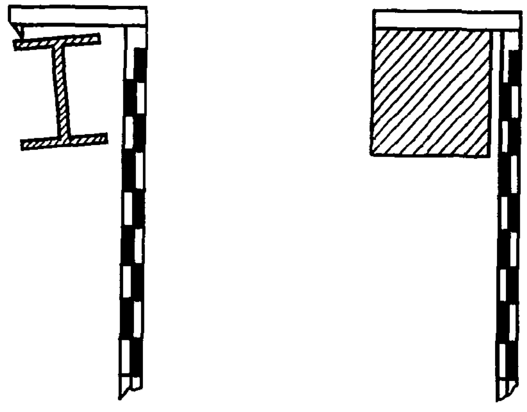


Figure 50

As shown in figure 52, surface indicating lasers can also be used for levelling.

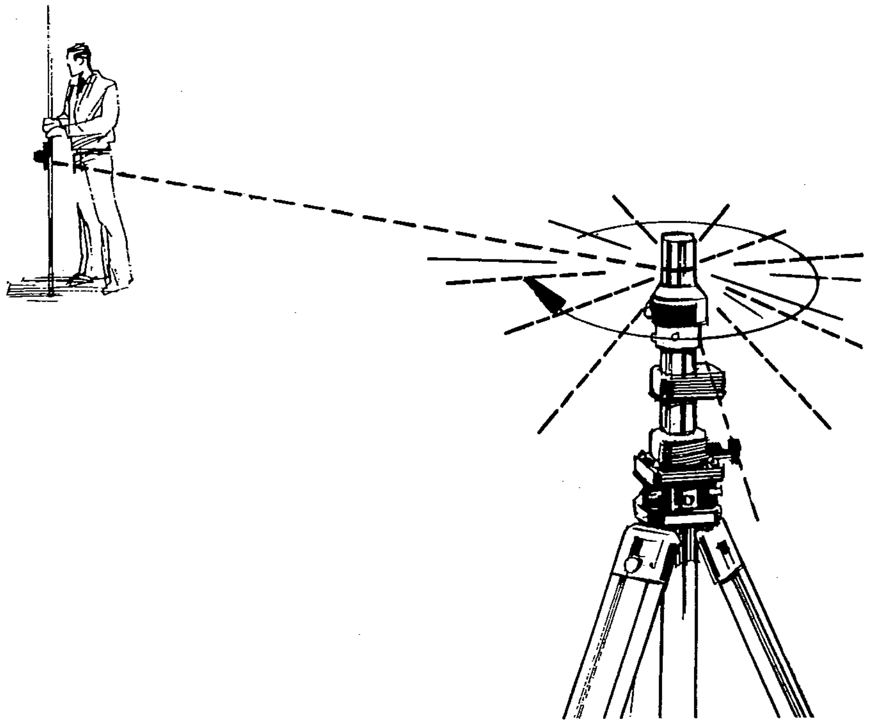


Figure 52

9.1 Accuracy table

Measuring operation	When values for permitted deviation specified for object exceed :	Measuring range	Measuring instrument or tool
1	2	3	4
Deviation from levels and heights (clause 9)	± 2 mm	< 30 m	Levelling instrument with parallel plate micrometer and staff
	± 4 mm	< 30 m	Levelling instrument and staff
	± 10 mm ± 15 mm ± 20 mm	< 10 m 10 to 30 m 30 to 70 m	Surface indicating laser

10 Verticality

Verticality can be determined with the aid of

- theodolite;
- optical plumbing instrument;
- inclinometer;
- plumb bob.

Deviations from verticality shall generally be determined from two vertical reference planes perpendicular to each other. The verticality of multi-storey columns and buildings should be checked with theodolites (face left and face right) or optical plumbing instruments (in two positions). Theodolites used for this kind of check measurements should be provided with a spirit level with a sensitivity better than 60″.

10.1 Using a theodolite/optical plumbing instrument

As shown in figure 53, the checking of the verticality of walls can be carried out with the aid of a theodolite.

When the angle α exceeds 50 gon (45°), the plumbing should be carried out with the aid of an optical plumbing instrument. (See figure 54.)

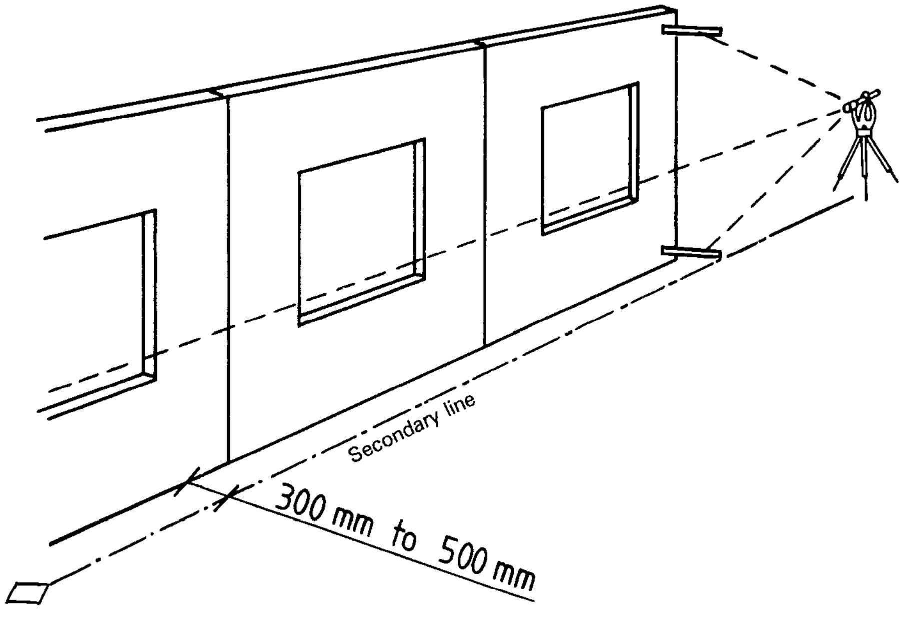


Figure 53

Dimensions in millimetres

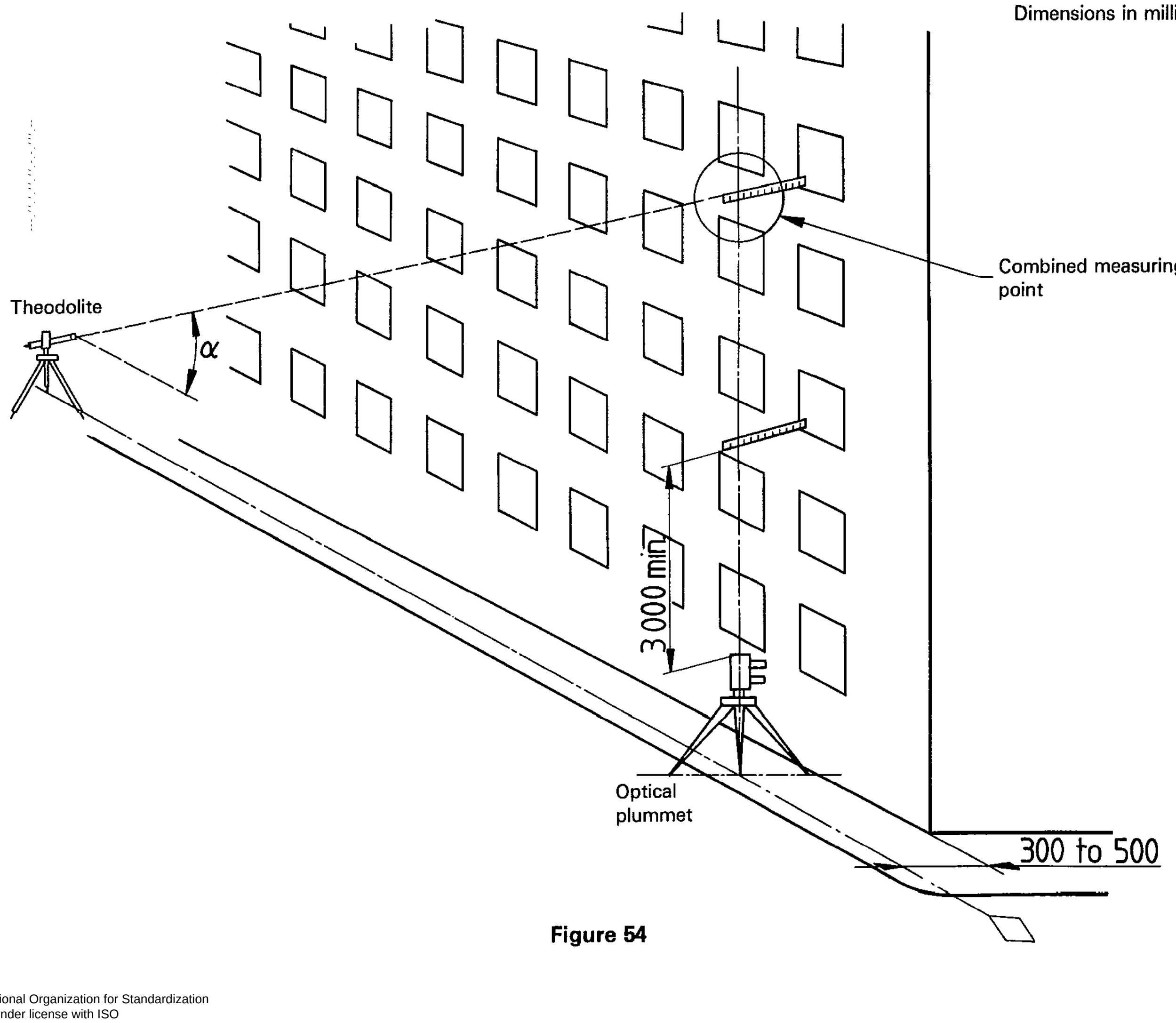
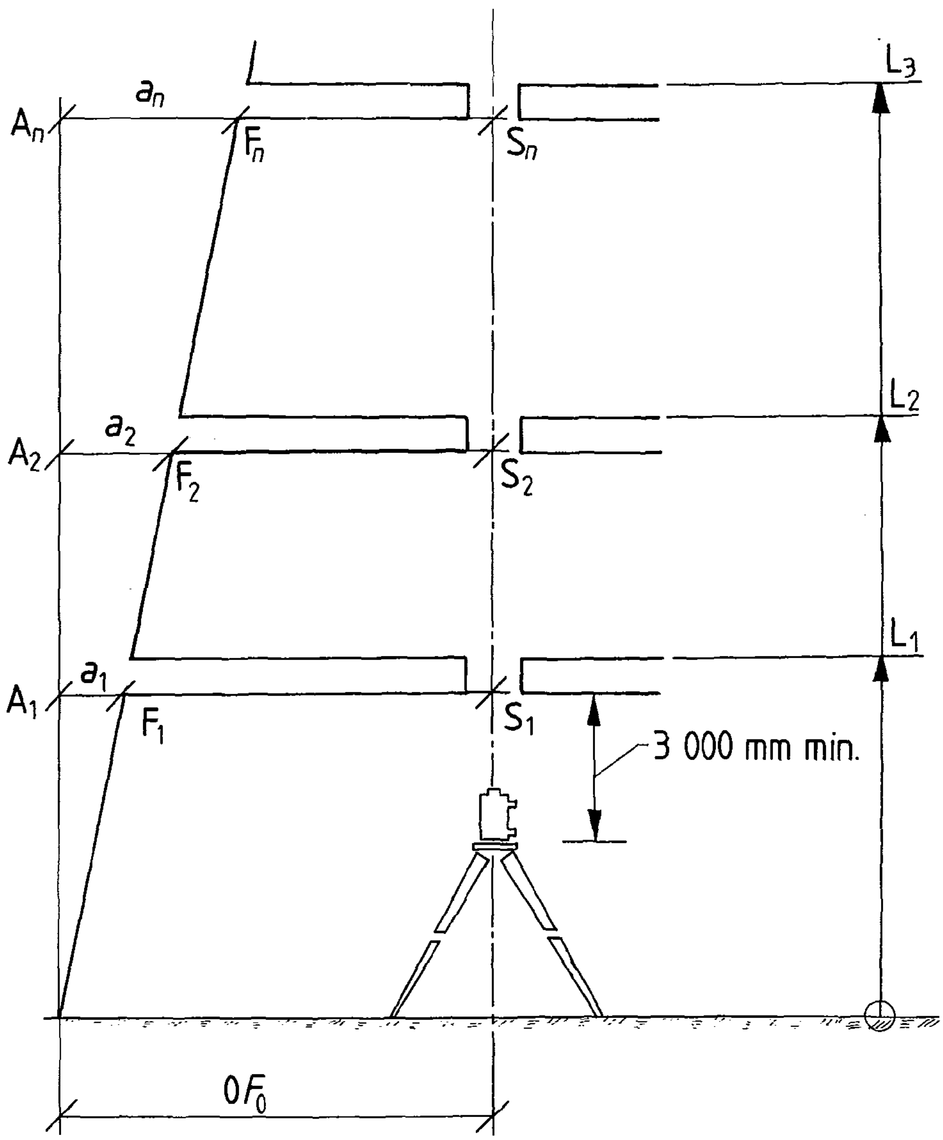


Figure 54

Figure 55 shows determination of the deviation from verticality using an optical plumbing instrument.



$0F_0$ = known distance
S_iF_i = measured distance
a_i = deviation from verticality = $0F_0 - S_iF_i$ over the height L_i

Figure 55

When checking the verticality of columns, either the edge of the column or its centre line is checked.

The theodolite is set up over one of two lines which intersect at right angles at one corner of the column at its base. It is best if these lines are parallel to the base lines and coincide with the sides of the columns. The theodolite is sighted so that the image of the top of the column edge just touches the crosshairs. The instrument is then rotated in the correct vertical plane down to the bottom of the column and the amount by which the column edge is away from the crosshair is noted on a measuring rod. The theodolite is then set up over the other line and the column is checked in the same way. The accuracy of this method is adversely affected by variations in the width of the column and by chamfered edges.

Figure 56 demonstrates checking the verticality of the sides of a multistorey column by using a theodolite.

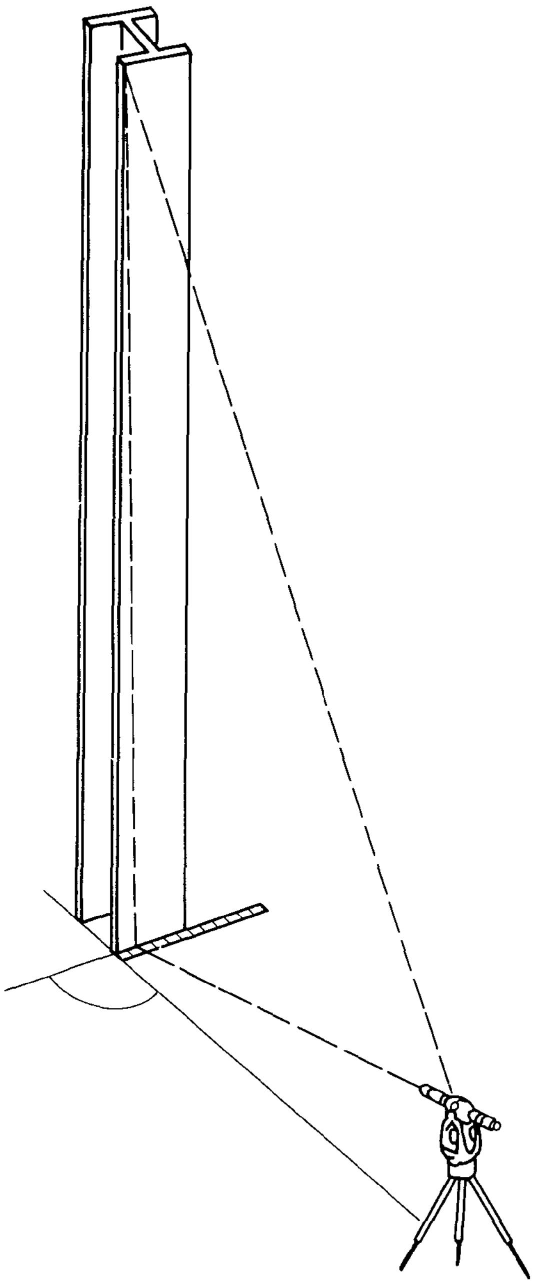


Figure 56

A more accurate method is to mark the centre-line of the column at the top and bottom on two adjacent sides before it is erected. The theodolite is then set up over two lines which intersect at right angles at the centre of the column. If possible these lines should be identical with the base line so that a position check can be made at the same time. The column is aligned so that its centre-line coincides with the vertical plane of the theodolite. The centre-line may be pieces of tape on which graduation marks have been printed and on which the deviation from verticality can be read off. It is important to check the operation by measuring in both faces of the theodolite.

Figure 57 demonstrates checking the actual centre-line position of the column against the centre-line marks on the column. If the centre of the column is marked at other places in addition to the top and bottom, deviation from straightness can also be determined.

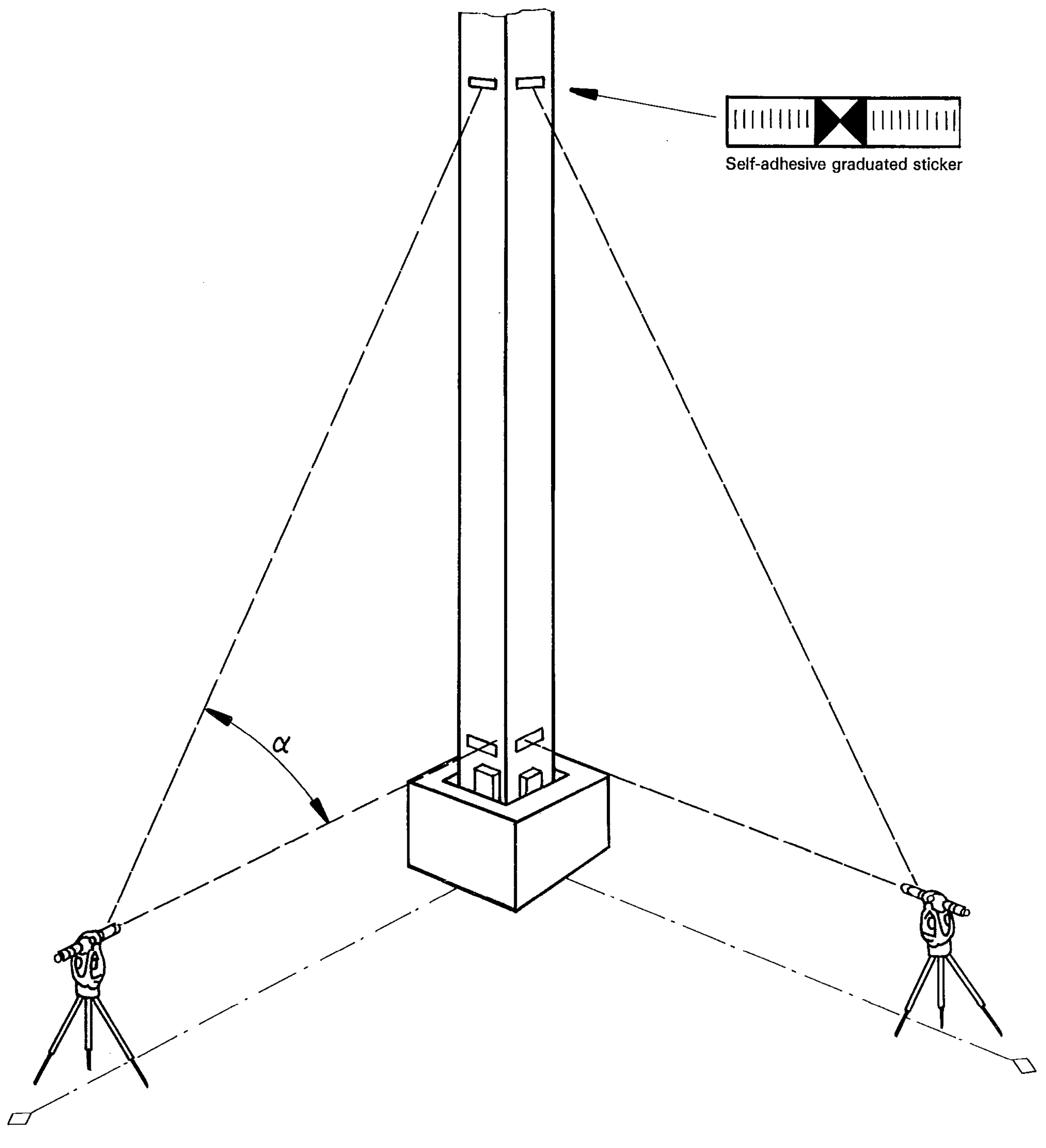


Figure 57

10.2 Using a clinometer

Clinometers are used for the measurement of deviations from verticality over heights up to normal room height. (See figure 58.)

All types should be so constructed that they can be reversed to eliminate systematic measuring errors of the spirit-level. It shall be possible to adjust the spirit-level. Clinometers shall be provided with studs to allow measuring along curved surfaces. (See figure 59.)

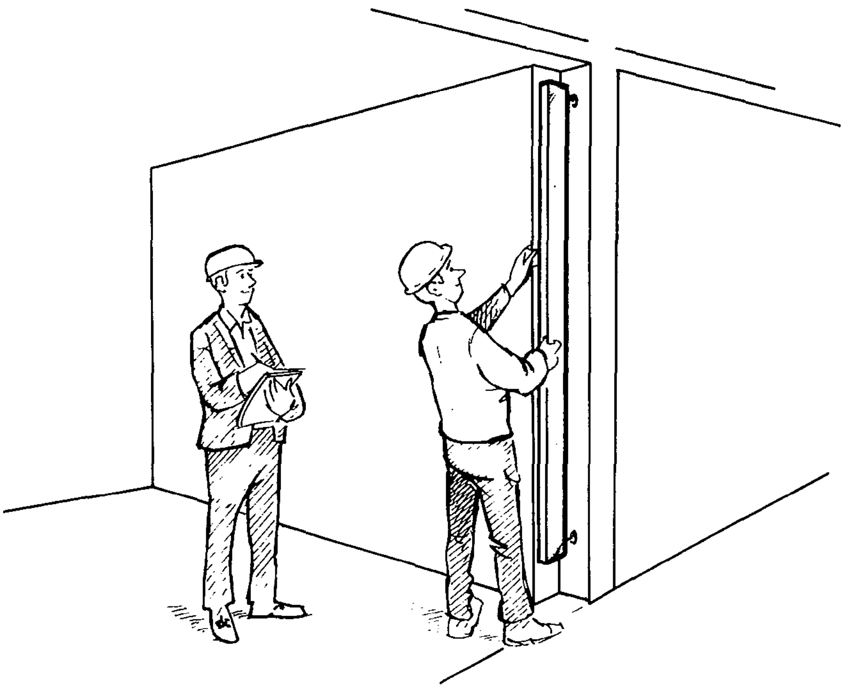


Figure 58

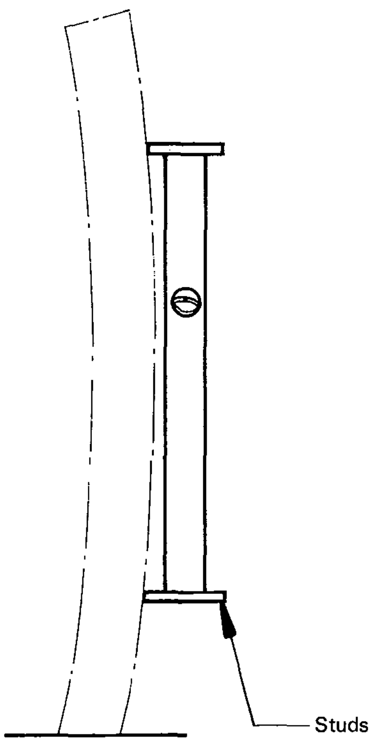


Figure 59

In general there are two main methods for the determination of deviations from verticality with the aid of a clinometer:

a) Indirectly, which implies transforming the number of divisions that the bubble of the spirit-level is displaced from its central position (see figure 60) into a vertical angular deviation expressed as an offset in millimetres per metre.

b) Directly, by reading the deviations from verticality on a movable scale after the bubble of the spirit-level has been brought into its central position, as shown in figure 61.

Accuracy of instruments should be as follows:

— spirit-levels of clinometers should have a sensitivity better than 3″;

— spirit-levels should be checked and when necessary be adjusted before use;

— clinometers shall be provided with studs;

— after the first measurement, the clinometer should be reversed and the measurement be repeated. The mean of the two readings gives the actual deviation;

— the flat side of the clinometer — that is the non-measuring side — shall be brought into the vertical. It is (usually) sufficient to do this with a spirit-level which is less sensitive than the main one.

NOTES

1 So-called builder's or carpenter's spirit-levels are not suitable for check measurements and therefore may not be used.

2 Since the sensitivity of spirit-levels can differ from that indicated by the manufacturer, it is recommended that spirit-levels with half the sensitivity value needed are chosen. For example, for a calculated or required value of sensitivity of spirit-level of 60″, use a spirit-level with a sensitivity indication of 30″.

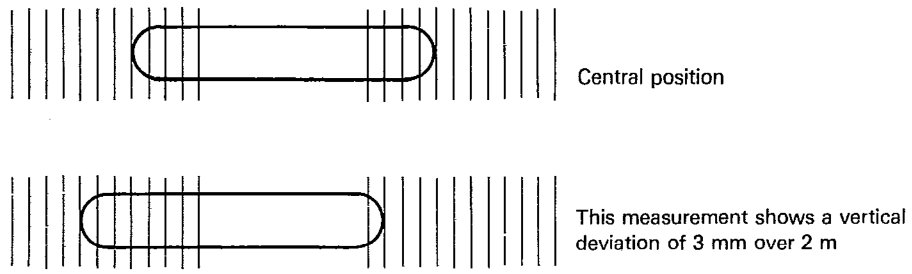


Figure 60

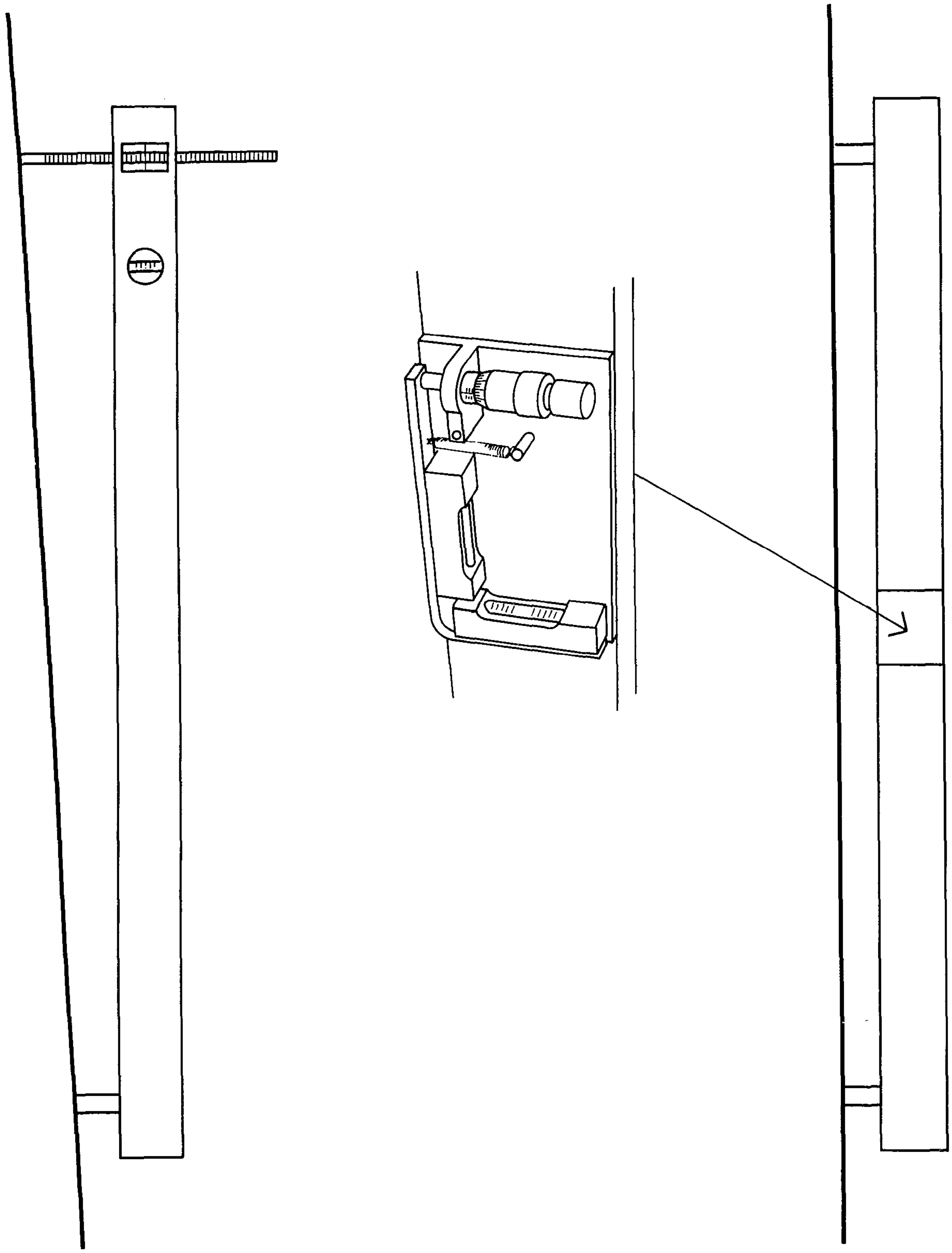


Figure 61

10.3 Using a plumb bob

Plumb bobs may give large measuring errors. However, the accuracy can be improved if the plumb bob has a mass of at least 1 kg and is submersed in an oil bath. (Water does not sufficiently dampen the oscillations of the plumb bob.)

Figure 62 gives an example of determination of deviation from verticality (A-B) with the aid of a plumb bob.

Extreme care to avoid spillage of oil on the floor should be exercised.

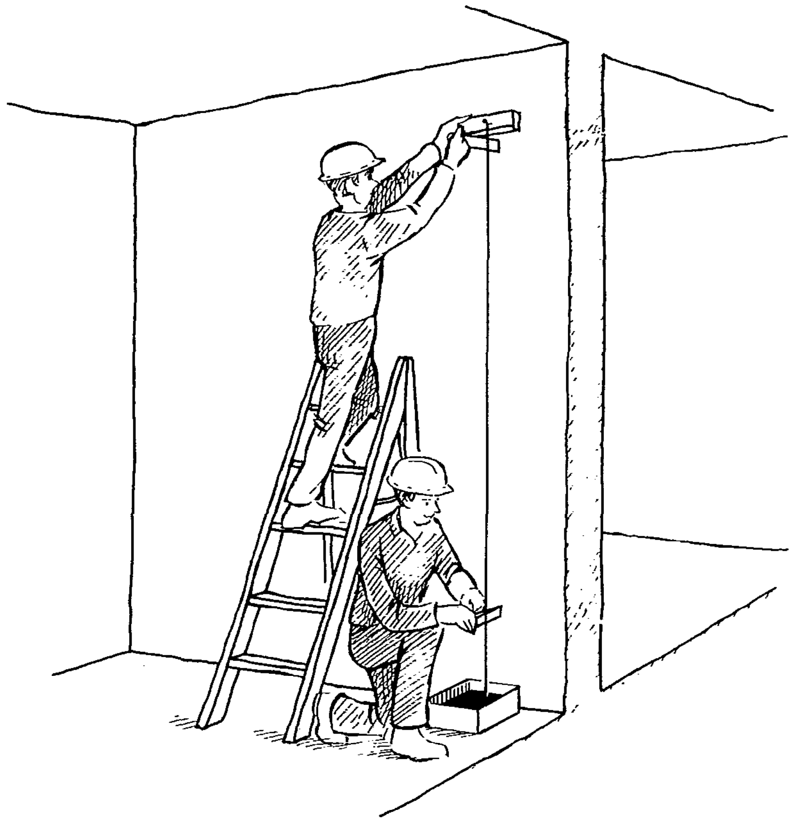


Figure 62

10.4 Accuracy table

Measuring operation	When values for permitted deviation specified for object exceed:	Measuring range[1)]	Measuring instrument or tool
1	2	3	4
Deviations from verticality:			
Theodolite/ optical plumbing instrument (10.1)[2)]	± 0,5 mm/m	< 100 m	Optical plumbing instrument
	± 0,8 mm/m ± 1,2 mm/m	α < 50 gon α = 50 to 70 gon	Theodolite and marked centre-line
	± 1 mm/m ± 1,5 mm/m	α < 50 gon α = 50 to 70 gon	Theodolite and rod or tape (along the edge)
Clinometer (10.2)	± 3 mm	< 2 m	Clinometer
Plumb bob (10.3)	± 8 mm ± 15 mm	< 2 m 2 to 6 m	Plumb bob and rule or tape

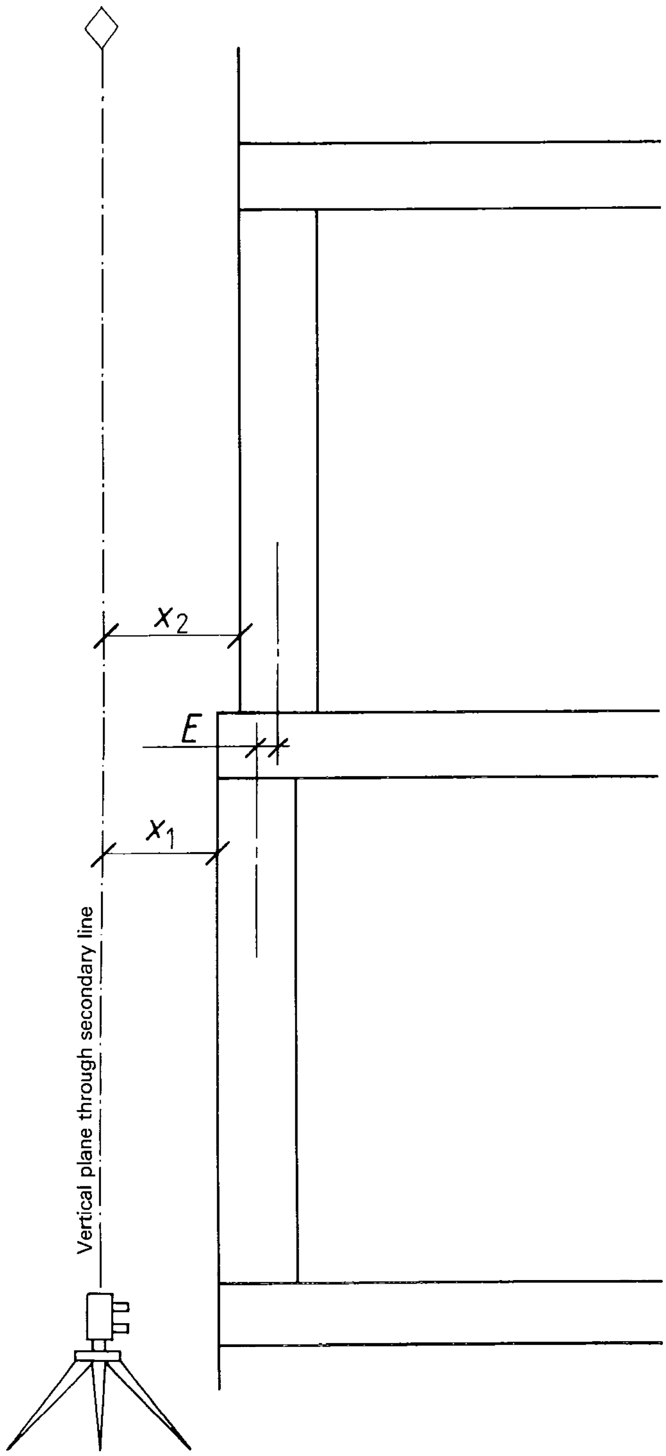
1) α = angle of elevation

2) When plumbing heights or the length of lines of sight of theodolites exceed 40 m the measurements should preferably be entrusted to well qualified personnel.

11 Eccentricity

Eccentricity can be defined here as those cases where a loadbearing component or building part is unintentionally situated in a different vertical plane from the component above or below it, which can cause a reduction in stability.

Figure 63 shows eccentricity between two loadbearing components.

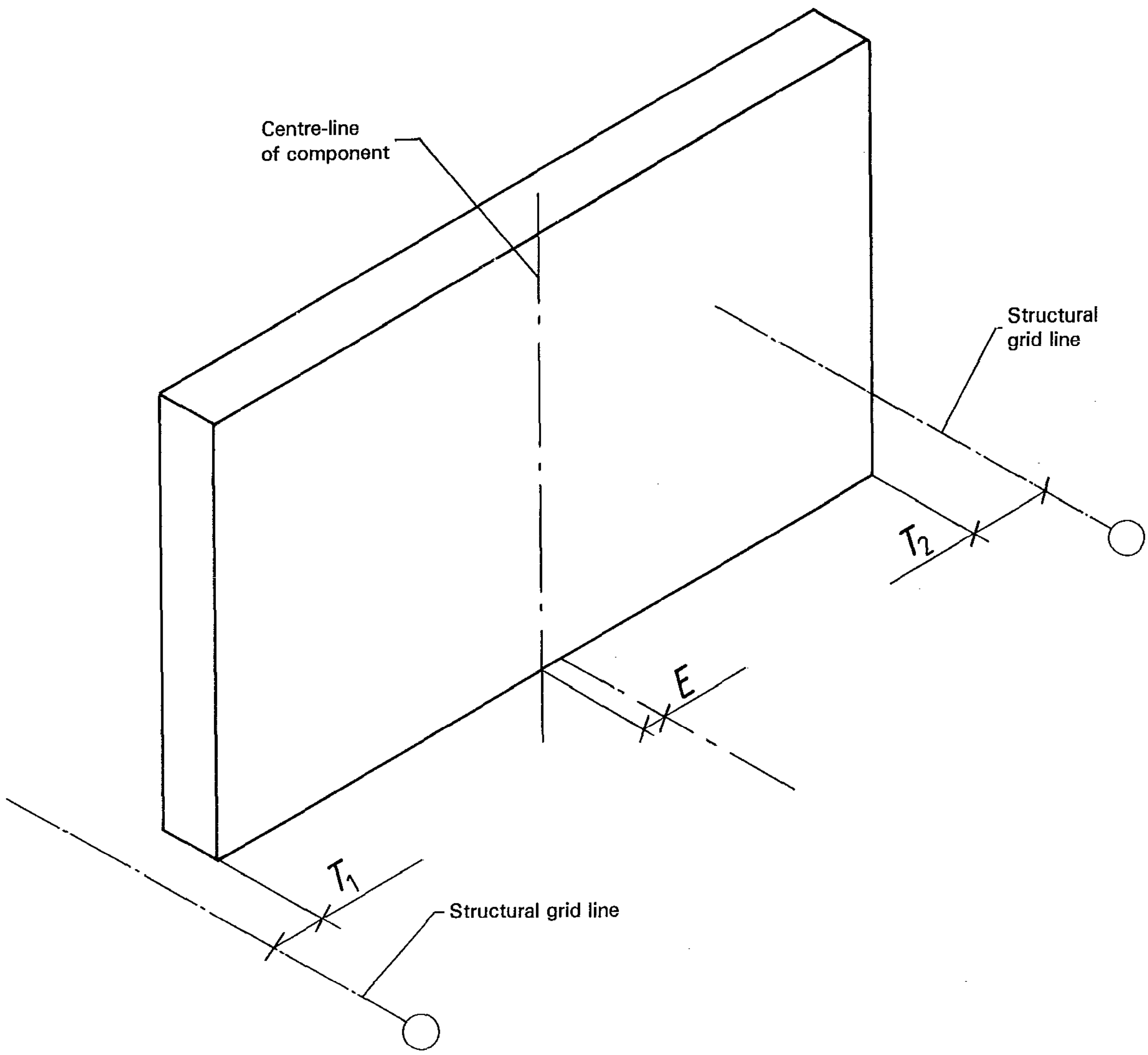


$E = x_1 - x_1$ if the thicknesses of the walls are the same.

Figure 63

The concept of eccentricity is sometimes also used to indicate the unintentional asymmetrical position of a component in relation to two structural grid lines.

Figure 64 shows determination of eccentricity in relation to two structural grid lines. T_1 and T_2 show position deviation.



$$\text{Eccentricity, } E = \frac{T_2 - T_1}{2}$$

Figure 64

11.1 Accuracy table

Measuring operation	When values for permitted deviation specified for object exceed:	Measuring range[1)]	Measuring instrument or tool
1	2	3	4
Eccentricity[2)] (clause 11)	± 0,5 mm/m	< 100 m	Optical plumbing instrument and rod
	± 0,8 mm/m ± 1,2 mm/m	α < 50 gon α = 50 to 70 gon	Theodolite and rod
	± 5 mm ± 10 mm ± 15 mm	< 10 m 10 to 20 m 20 to 30 m	Calibrated steel tape and square

1) α = angle of elevation (see for example figure 54).

2) When plumbing heights or the length of lines of sight of theodolites exceed 40 m the measurements should preferably be entrusted to well qualified personnel.

12 Position in relation to other components (openings and spaces)

The determination of positional deviations in relation to other components — such as dimensional deviations of rooms or of any other internal accuracies — can be calculated from the measuring values obtained from one or more methods above. Examples of some other methods are given below.

Distances between walls and between columns can be measured with telescopic measuring rods. Care shall be taken that perpendicular distances and not inclined ones are measured. Telescopic measuring rod should be placed at right angles. (See figure 65.)

When using measuring tapes, distances between walls in closed spaces can normally only be determined at floor level using auxiliary marks at short distances from the walls. (See figure 66.)

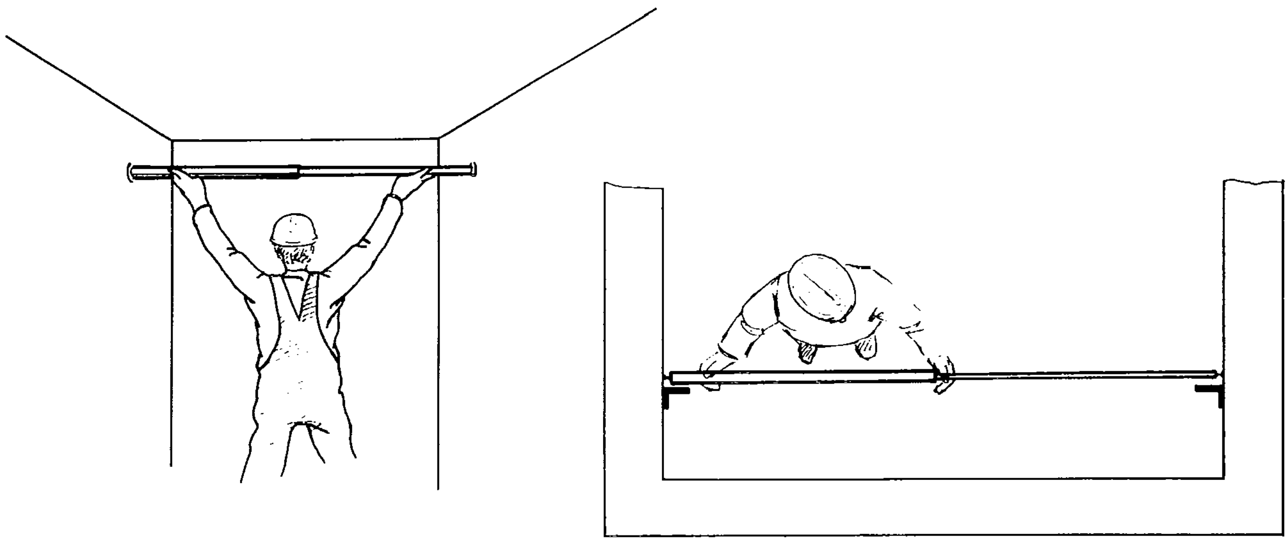


Figure 65

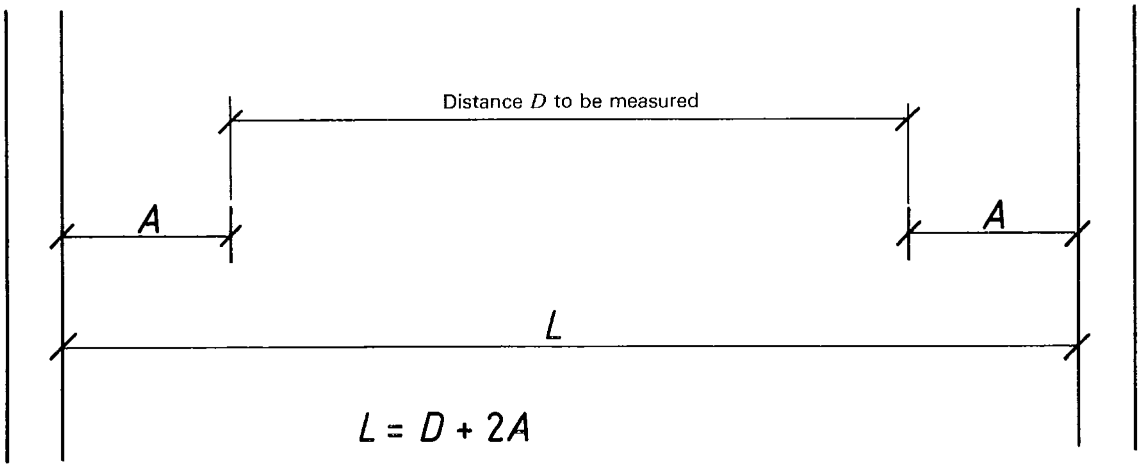


Figure 66

Direct measurement between walls at ceiling level should be avoided for heights larger than 3 m; they shall be measured indirectly, for example with the aid of a spirit-level, clinometer, optical plumbing instrument or theodolite. (See figure 67.)

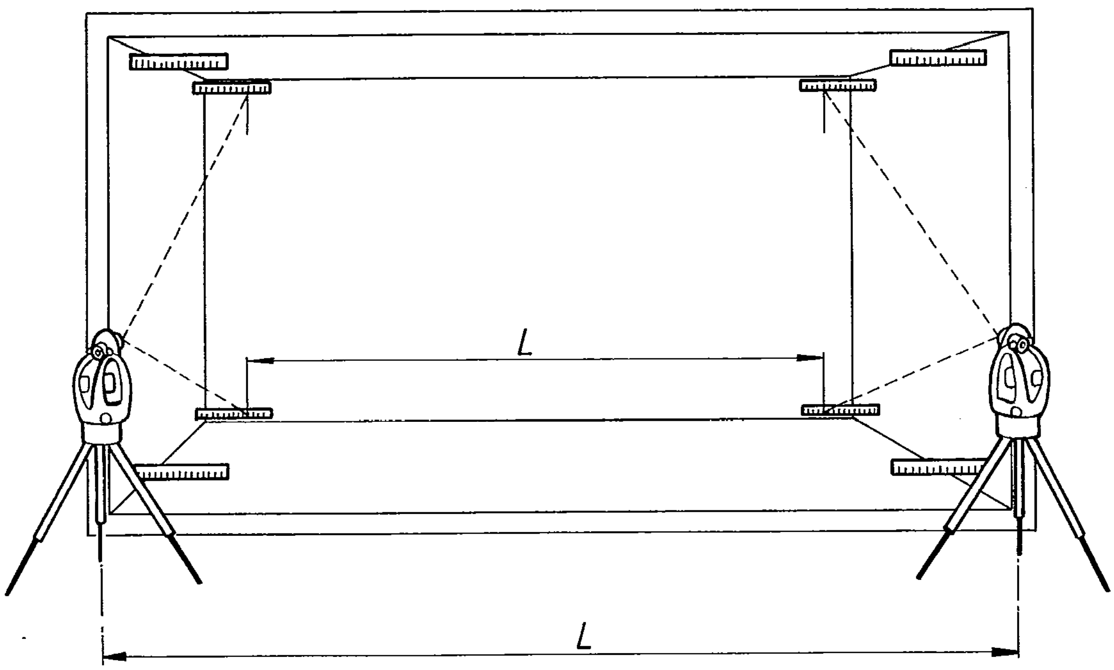


Figure 67

As shown in figure 68, the relative positions of columns can be determined using measuring tapes and position pieces.

Measuring the floor width with the aid of a measuring tape and two squares is shown in figure 69.

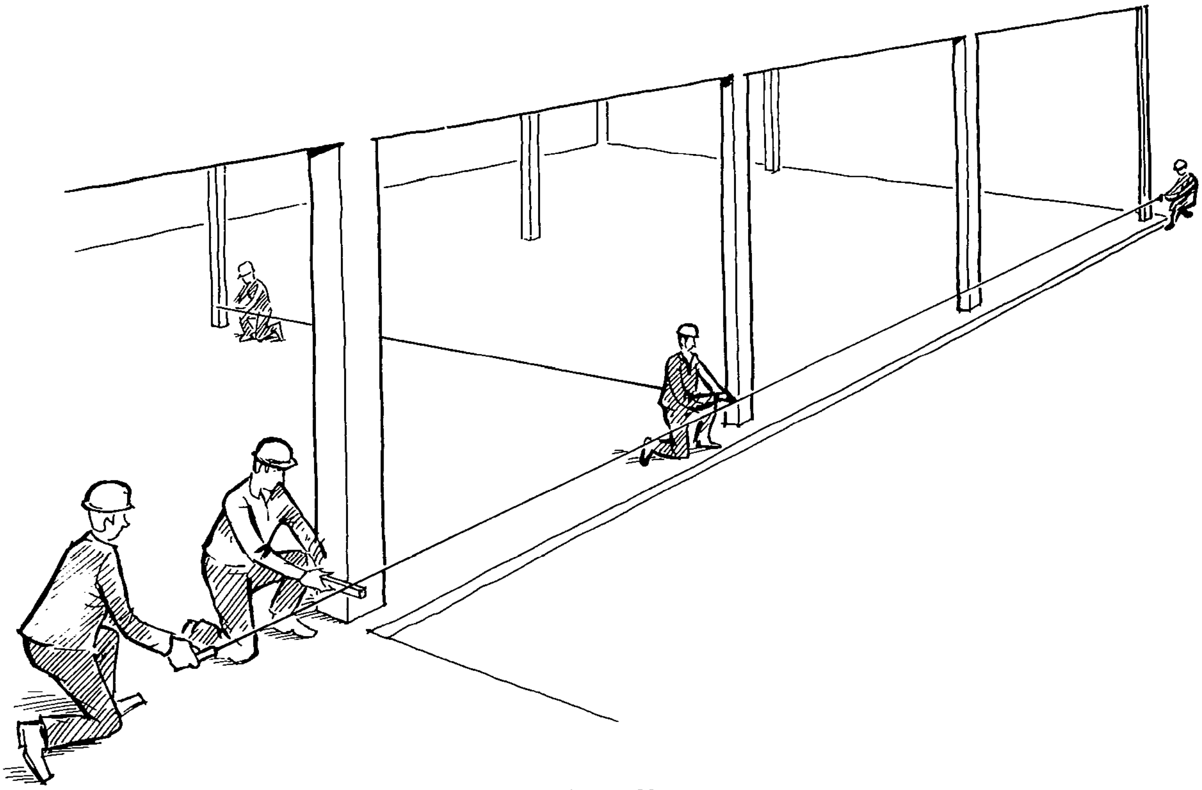
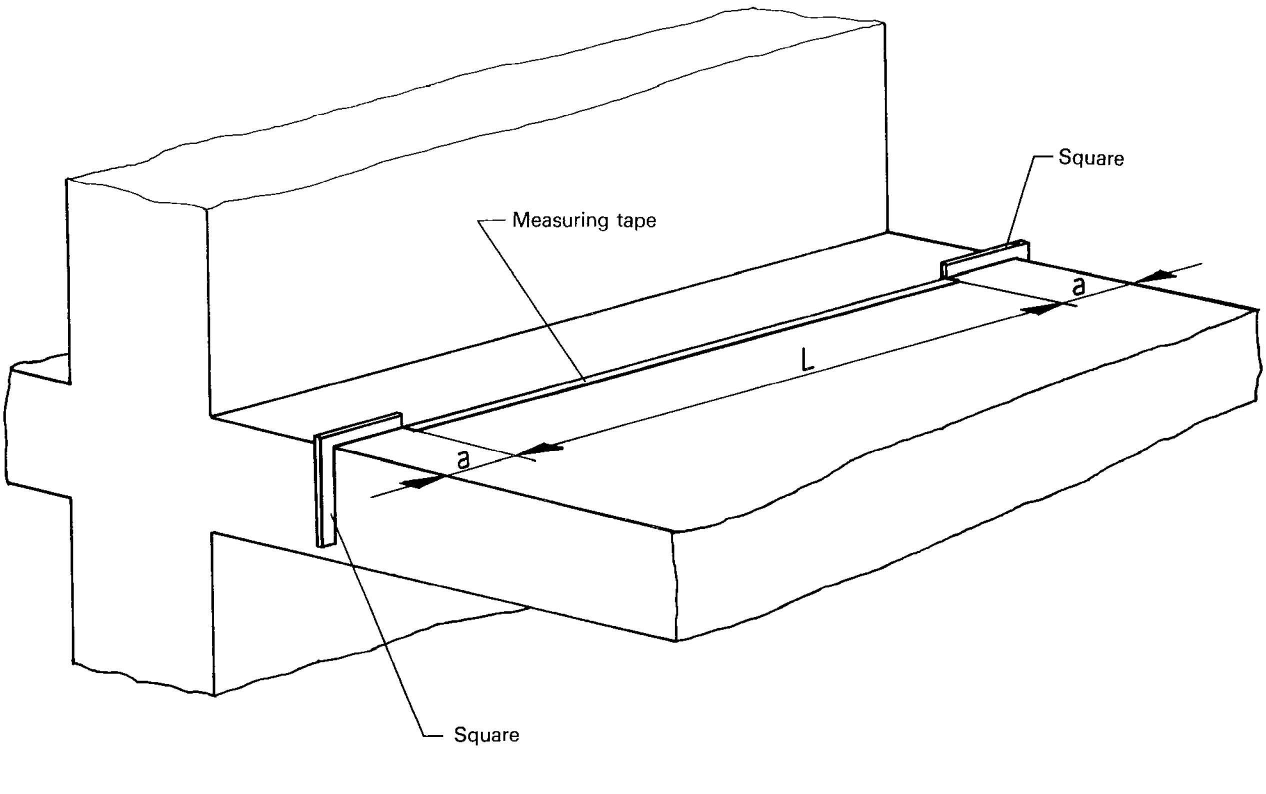


Figure 68



Floor width $= L + 2a$

Figure 69

Height measurements can be made directly with a pocket tape or a telescopic measuring rod. (See figure 70.) Care should be taken that vertical distances and not inclined ones are measured. For a room height of 3 m, the plumb line deviation of the tape or the staff shall not exceed 50 mm.

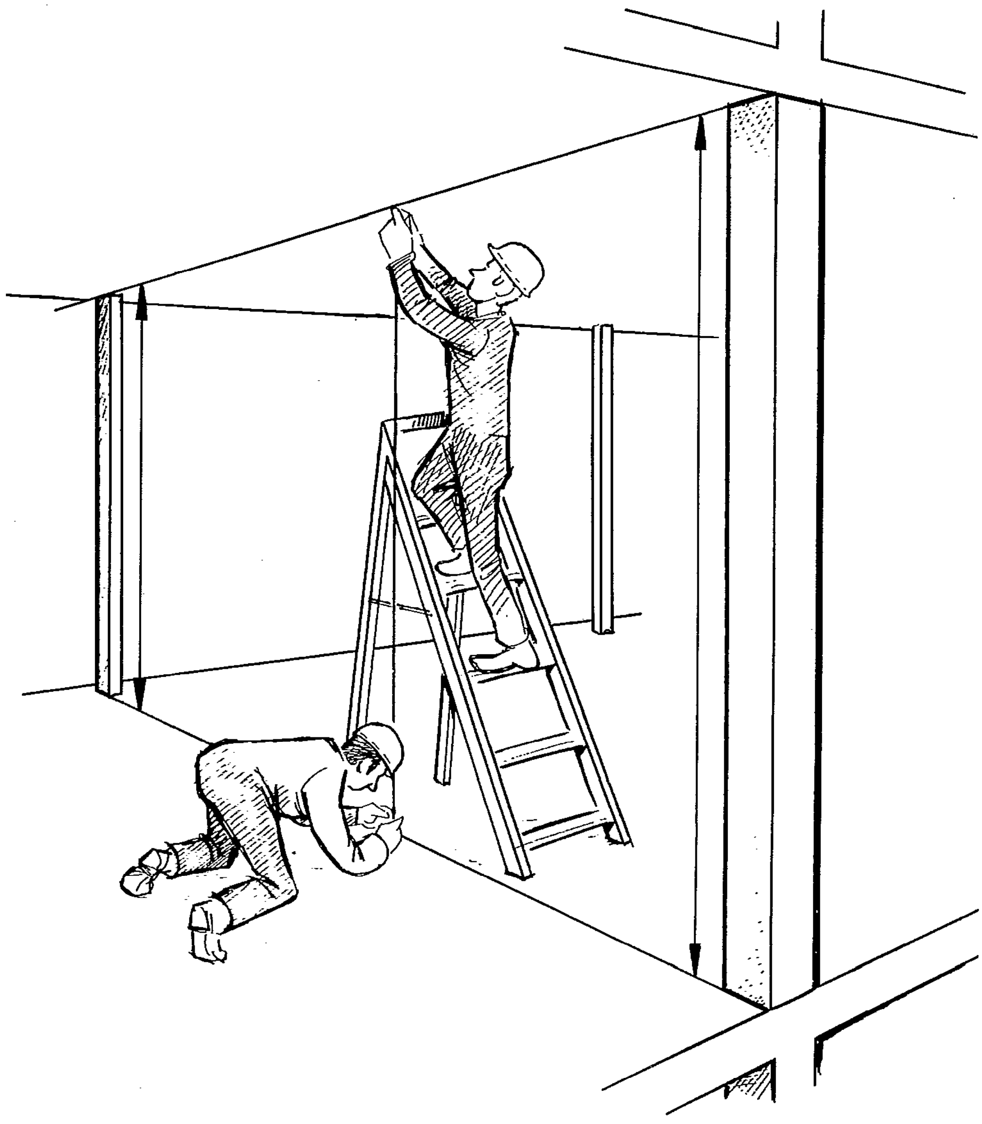
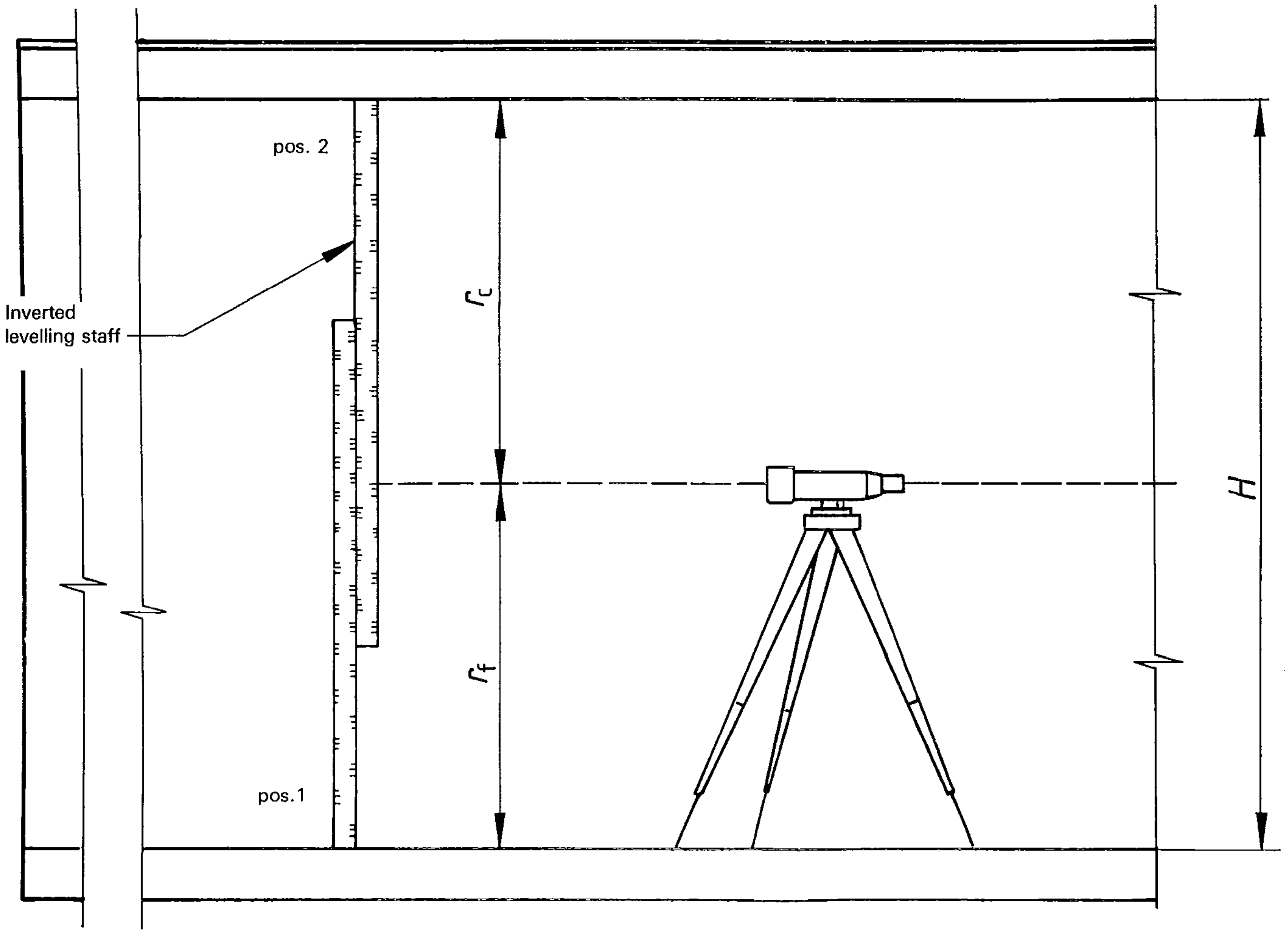


Figure 70

Figure 71 shows indirect height measurement with the aid of a levelling instrument. This measurement can be combined with the levelling of floors and ceilings. (See figure 49.)



Example: Height of room H = reading towards floor plus reading towards ceiling ($H = r_f + r_c$)

Figure 71

The readings on the staff shall be corrected for possible zero error. A zero error occurs if the zero point of the staff does not coincide with the bearing end of the staff. (See figure 72.)

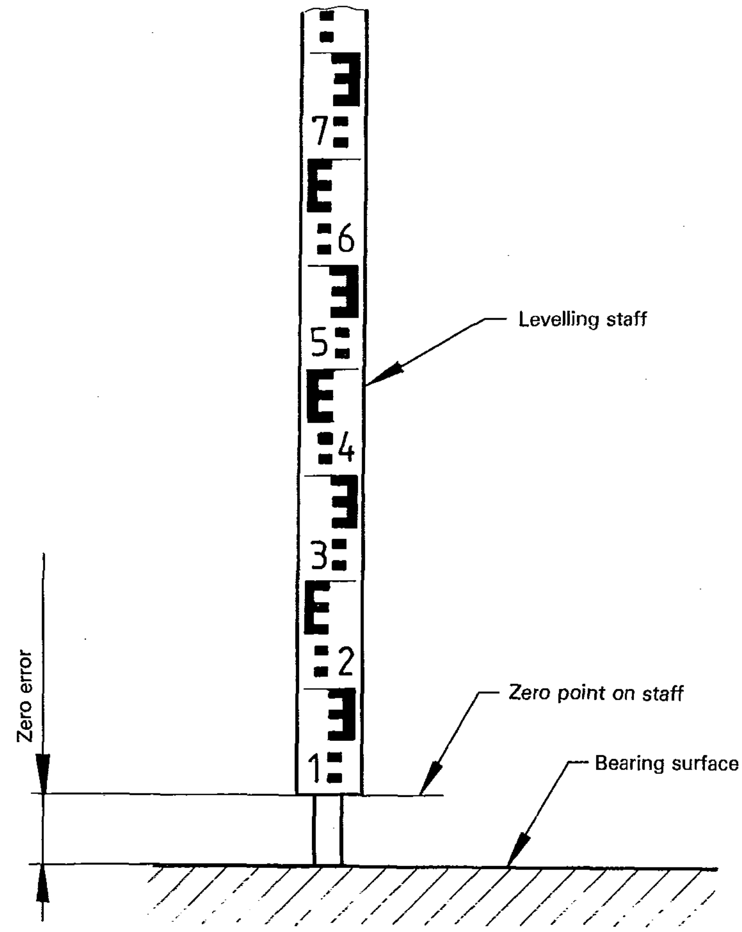
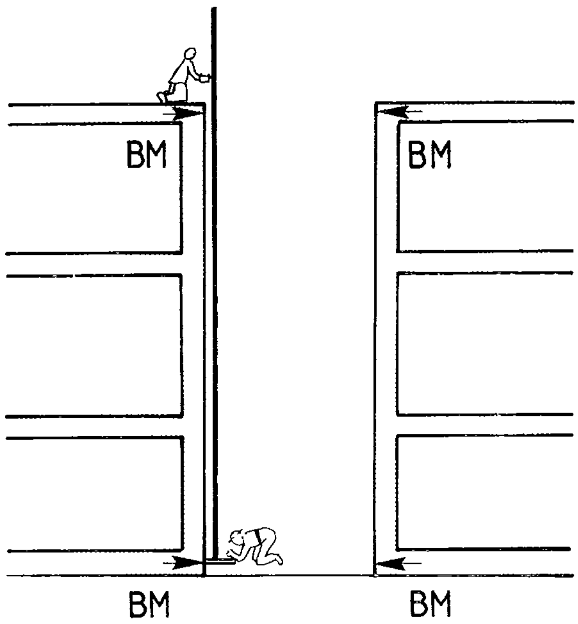


Figure 72

When measuring the heights of openings or transferring levels with a measuring tape the calibration tension and corrections for temperature shall be applied when the height exceeds 10 m, for instance a lift (elevator) shaft. (See figure 73.)



BM = bench mark

Figure 73

For high buildings EDM instruments can be used as shown in the example below. The difference in height can be measured either directly along a plumbline or indirectly by reducing a slope distance by determining the vertical angle. Figure 74 shows the set-up of instrumentation necessary for the determination of height differences between bench marks in floors of buildings and for which additional measurements have to be made. The total difference in height between the points is

$$\Delta H = A_{FU} - A_{FO} - A_D + A_K + L - K + K_S + K_{BR}$$

where

FO, FU are bench marks;

ΔH is the height difference between the two benchmarks;

L is the long distance (MNQ);

K is the short distance (MN);

K_S is the constant height of the mirror's trunnion axis above tribach;

K_{BR} is the constant height of the reflector's trunnion axis;

A_K, A_D, A_{FO}, A_{FU} are readings on a levelling rod.

This method allows for cancellation of the instrument constant.

Figure 74 shows height measurement with the aid of an EDM instrument.

NOTE — The measurements are complicated and should therefore be carried out by well qualified personnel.

In figure 74 the vertical distance ΔH is derived with the aid of the difference between two distance measurements (MNQ − MN). This method eliminates the zero-error of the EDM-instrument. For the method in figure 75 only one distance measurement is necessary, but here the zero-error must be known or investigated.

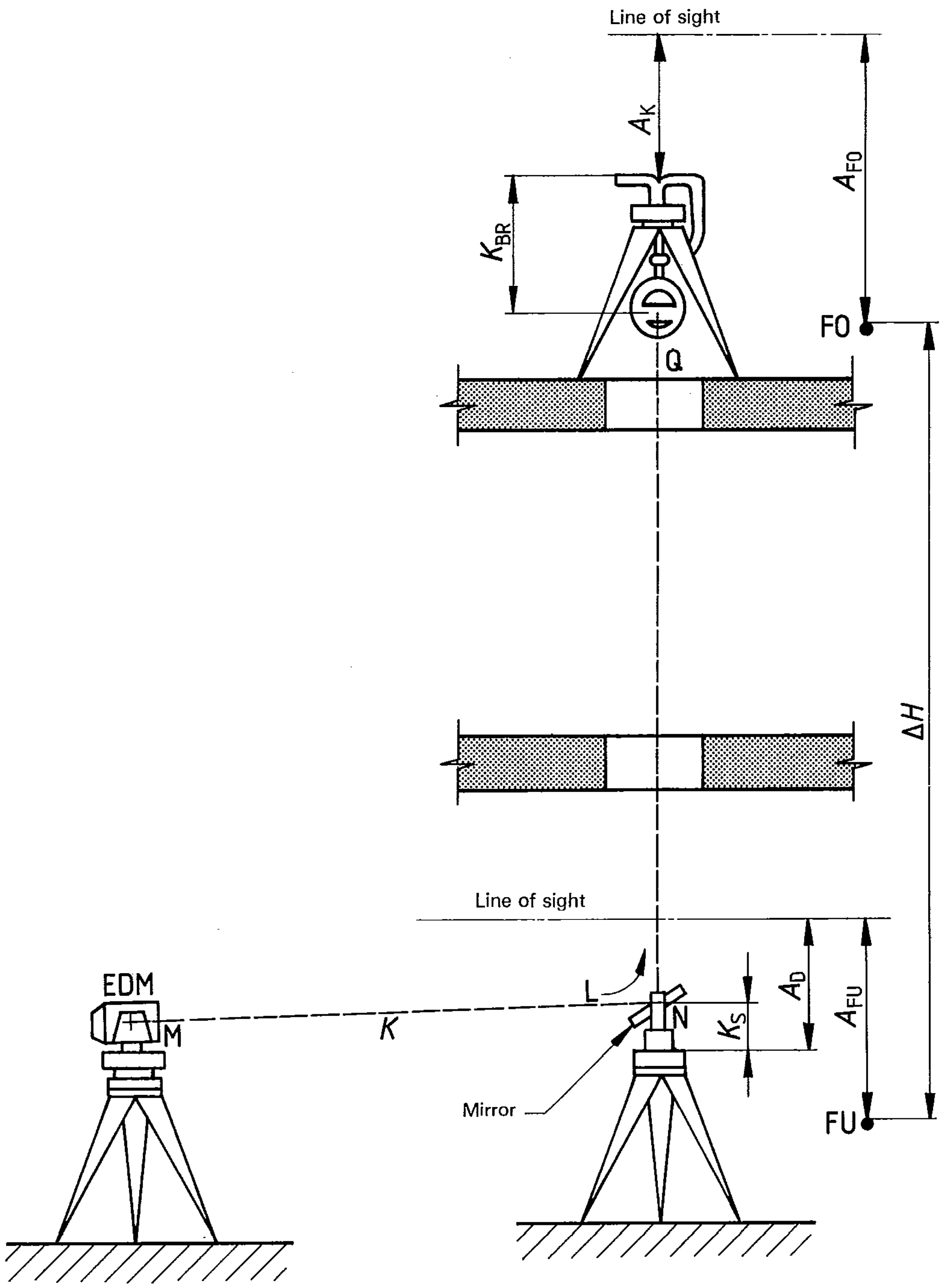
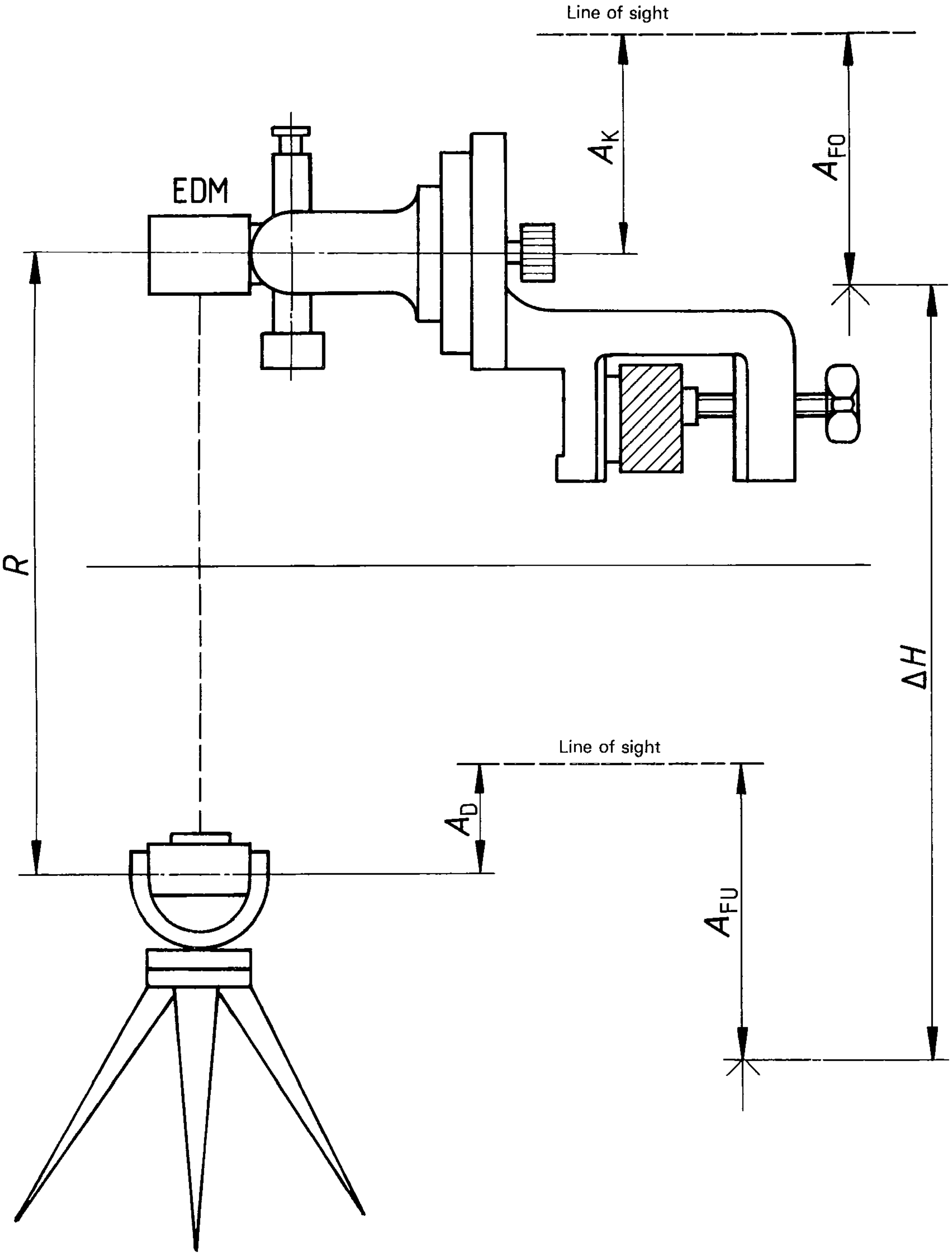


Figure 74

A method for a more direct procedure is shown in figure 75.



$$\Delta H = R + A_K + A_{FU} - A_D - A_{FO}$$

Figure 75

12.1 Accuracy table

Measuring operation	When values for permitted deviation specified for object exceed:	Measuring range	Measuring instrument or tool
1	2	3	4
Positional deviation in relation to other erected components:			
Horizontal	± 5 mm	< 5 m	Telescopic measuring rod
	± 5 mm ± 10 mm ± 15 mm ± 20 mm	< 10 m 10 to 20 m 20 to 30 m 30 to 50 m	Calibrated steel tape and rule or retractable steel tape
	± 5 mm ± 10 mm ± 15 mm ± 20 mm	< 10 m 10 to 20 m 20 to 30 m 30 to 50 m	Theodolite measuring rod and calibrated steel tape
	± 5 mm ± 10 mm ± 15 mm ± 20 mm	< 10 m 10 to 20 m 20 to 30 m 30 to 50 m	Calibrated steel tape
	± 5 mm ± 10 mm ± 15 mm ± 20 mm	< 10 m 10 to 20 m 20 to 30 m 30 to 50 m	Calibrated steel tape and square
Vertical	± 5 mm	< 5 m	Telescopic measuring rod or retractable steel tape
	± 5 mm	< 5 m	Levelling instrument and staff
	± 8 mm	< 100 m	EDM
	± 5 mm ± 10 mm ± 15 mm ± 20 mm	< 10 m 10 to 20 m 20 to 30 m 30 to 50 m	Calibrated steel tape

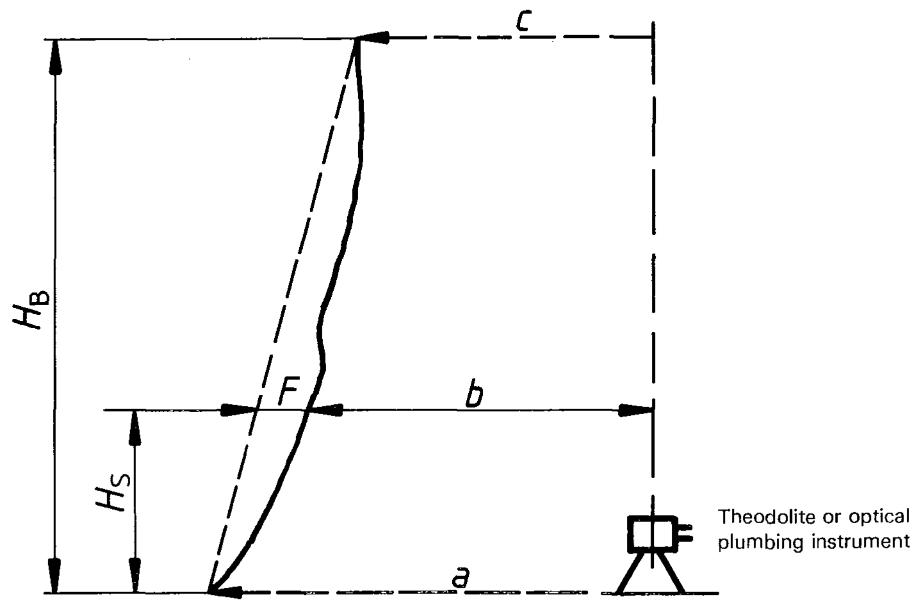
13 Flatness, straightness, designed camber

The measuring values obtained from the measuring procedures described in clauses 6, 9 and 10 can also be used when determining construction deviations from flatness, straightness or designed camber according to the principles in clauses 6 and 7. However, for these cases it shall also be agreed to which reference plane the deviations are to be related (see clause 7).

Flatness deviation (overall or local) is determined in relation to an agreed reference plane, for instance as in this simplified example a plane through points in a façade at ground and roof level. (See figure 76.)

13.1 Accuracy table

For information on the accuracy for a specific measuring method used when determining deviations from flatness, straightness and designed camber, see accuracy tables in clauses 6, 7, 8, 9 and 10.



a, b and c are measured values

H_B is the height of the building

H_S is the storey height

F is the flatness deviation

$$F = (a - b) - \frac{H_S}{H_B}(a - c)$$

Figure 76

14 Other important deviations

14.1 Length of bearing surface

Lengths of bearing (see figure 77) of floor units are mostly difficult to check after the floor units have been placed in position. A method of avoiding this difficulty is to set out a line parallel to the end of the floor unit at a distance (C), prior to assembly, and to mark this line, at two or more places, by a sharp scratch and, when allowed, mark the position of this scratch with a spot of paint so that it can be found easily. Measure after assembly the distance (M) between the mark on the floor unit and the bearing unit.

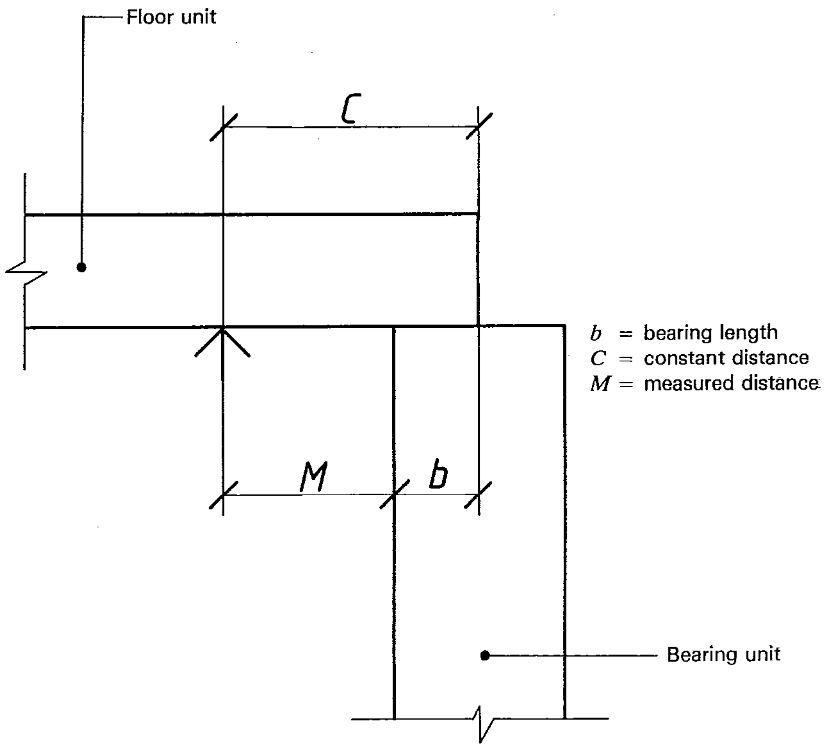


Figure 77

14.2 Joint width

The measurement of the widths of joints can be made with measuring wedges, internal calipers or measuring magnifiers. Go/No Go gauges are sufficient for compliance measurement but not for accuracy data collection measurements. If the joint has a bevel of more than 10 mm it is difficult to obtain a reading from a measuring wedge, due to parallax. In such cases an internal caliper or a feeler gauge can be used.

14.3 Joint step

A joint step can be measured during one of the measuring operations given, for example in figures 44 and 50, or determined separately with the aid of a set square or ruler and a retractable measuring tape, as shown in figure 78.

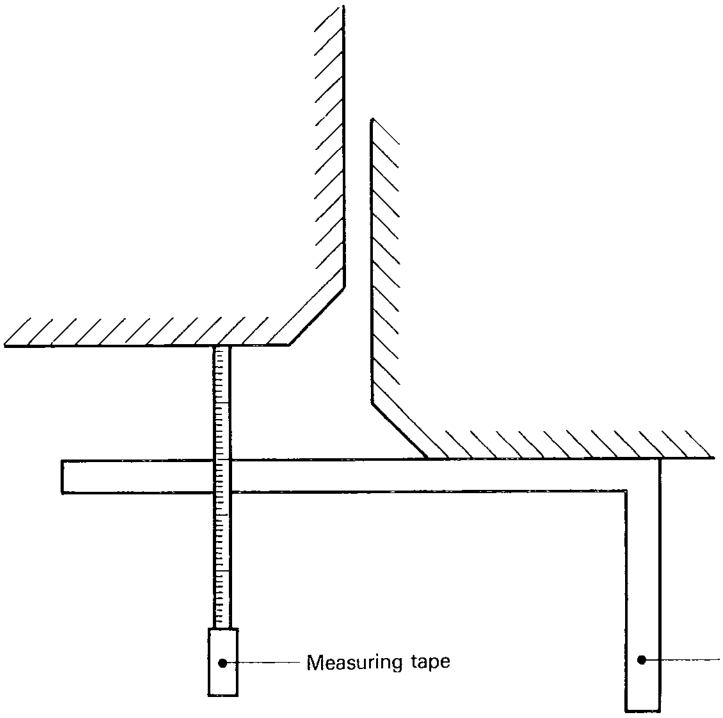


Figure 78

14.4 Accuracy table

Measuring operation	When values for permitted deviation specified for object exceed :	Measuring range	Measuring instrument or tool
1	2	3	4
Bearing length	± 6 mm	< 200 mm	Measuring tape
Joint width	± 0,5 mm	All normal sizes	Inside caliper
	± 2 mm	Joint range < 30 mm	Measuring wedge
	± 2 mm	Joint range < 30 mm	Go/No Go gauge
	± 5 mm	Joint range < 30 mm	Measuring tape
Joint step	± 5 mm	Joint range < 30 mm	Measuring rod

Section three: Measuring instruments

15 Measuring instruments

15.1 General

This clause gives some guidelines on measuring instruments and measuring tools suitable on building sites, and in factories for the measuring of buildings or building products.

The choice of instrument generally depends on the measurement task to be performed and on the specified permitted deviation. (See ISO 8322, parts 1 to 8.)

It should be noted that conditions in factories and on building sites can cause serious disturbances in the functions of instruments and measuring tools. They shall therefore be checked frequently and be cleaned immediately after use. Measuring instruments and tools should also be checked before they are used for the first time and after storage and repair.

Measuring instruments other than those mentioned in this International Standard — which may be more readily available in some countries — may be used on condition that they comply with the accuracy requirements of the method.

It is assumed that measuring instruments are in a good state of permanent adjustment, and that personnel have adequate training to manage the equipment they are to use.

Instrument instruction books should be read in order to familiarize operators with the instruments.

15.2 Sliding calipers and slide gauges (example in figure 7)

Sliding calipers or slide gauges are used for the measurement of sizes up to 1 000 mm.

It is practical to use calipers with jaws the faces of which are so formed that both inside and outside measurements can be made. Where there are two scales, care should be taken to read the correct one.

Take into account the following:

a) Wear and excess pressure can cause play and deformation of the jaw.

b) Required pressure can be checked by use of gauge blocks.

c) Extensive use on concrete products can cause wear of the faces of the jaws.

d) Calipers must be located perpendicular to surfaces of the object to be measured.

e) A locking device is needed to avoid disturbance of the setting.

f) The parallelism of the faces for external measurement should not be affected by clamping the slides.

g) Care is required to read the correct scale.

15.3 EDM (electro-optical distance measuring) instruments

EDM instruments are used for the direct measurement and setting out of distances greater than 30 m. The majority are theodolite-mounted while some have built-in distance and angle devices. There are also models which directly transform the measuring values into information about the horizontal distance and difference in height. They are often called "total stations".

Operation should be by well qualified personnel.

Take into account the following:

a) Before use, read the instruction manual for the equipment in question. Many errors arise due to unfamiliarity with the instrument.

b) Check frequently against relevant distances.

c) Before measurement it is recommended to allow several minutes after "switch-on" for warm-up and stabilization.

d) Atmospheric influences (pressure and temperature) are a source of error.

e) Zero, scale and cyclic errors should be checked periodically.

f) Centring and pointing errors will occur.

15.4 Go/No Go gauges (see figure 79)

Go/No Go gauges are used for measurement of the acceptability or otherwise of joint gap width range. They are manufactured from steel, hardwood or other rigid materials.

Acceptability is indicated if the minimum gauge will enter and the maximum will not.

Take into account that care is required to avoid confusion when different gauge sizes are in use.

NOTE — Go/No Go gauges are not acceptable for collecting measurement accuracy data.

15.5 Clinometers (inclinometers)

Clinometers (often called inclinometers when used to determine verticality in buildings) are used for the measurement of deviations from verticality (plumb line deviations), horizontality or designed slope for heights or lengths up to normal storey height. They can range from simple measuring tools with a spirit-level in a frame (for example a builder's level) to complicated ones with micrometer screw fittings.

Take into account the following:

a) An accuracy test must be carried out to determine whether the inclinometer in question can fulfil the accuracy requirements.

b) Ensure that the instrument is so constructed that it can be reversed to eliminate spirit-level errors.

c) Accuracy in use depends to a high degree on the sensitivity of the spirit-level. (See example in 10.2.)

15.6 Laser instruments

Laser instruments are used for the determination of heights/levels or deviations from position or direction. The reference lasers used in building production are so-called low-power (Helium-Neon gas) lasers.

Take into account the following:

a) Before use, read the instruction manual for the equipment in question. Many errors arise due to unfamiliarity with the instrument.

b) Whenever using lasers place warning signs according to national and local safety directions.

c) Although the term "low-power" means there is no hazard to the skin or clothes, it is still necessary to avoid looking directly into the beam.

d) Never use field glasses to find the position of the beam.

e) Remember that laser light is affected in the same way as any other light beam.

f) Check frequently for the position and direction of the laser and that the shutting-off function against inclined planes in horizontal rotating lasers operates.

g) Detector units should be regularly checked, for, for instance, low batteries.

h) Allow about 15 min for beam stabilization after "switch-on".

i) Measuring lengths should normally be restricted to 80 m.

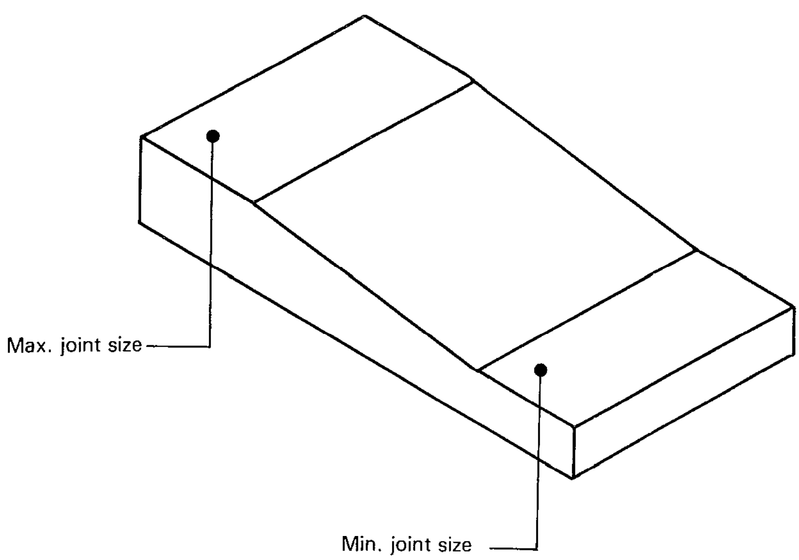


Figure 79

15.7 Spirit-levels

Spirit-levels are used to detect small differences in level over short distances (< 2 m) with or without a straightedge. (See figure 80.)

Take into account the following:

a) Observations must be carried out twice; after the first observation the level must be reversed.

b) The spirit-level is inaccurate and laborious over long distances.

c) It is not to be used for collecting accuracy data.

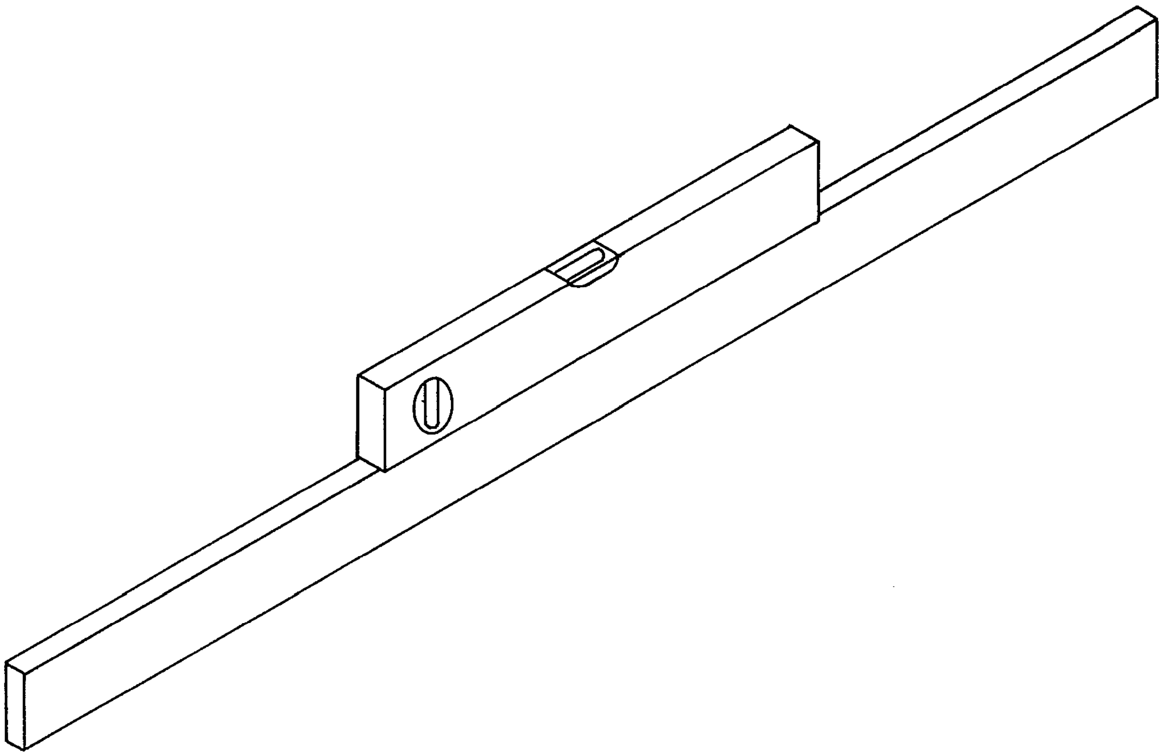


Figure 80

15.8 Water levels

Simple types of water levels may be used where other methods prove impractical, for instance around obstructions.

Take into account the following:

a) Air bubbles or cracks may occur in the flexible tubing which connects the glass tubes.

b) Zero errors on the scale may occur.

Different types of water levels are available (see figure 81), for instance:

a) the conventional;

b) a water level in which it is only necessary to read the level in one of the tubes.

15.9 Levelling instruments

The most common means of determining the height of a point relative to a reference datum, or deviation from horizontality, or flatness deviations of floors and building components and skewness is a levelling instrument.

There are three main types:

a) a dumpy level where telescope and vial are attached directly to the spindle which supports them;

b) tilting level where telescope and vial can be tilted by a screw through a small angle with respect to the spindle support;

c) compensation instrument in which the sighting axis is brought automatically into the horizontal position when the telescope has been set nearly horizontal.

Take into account the following:

a) Back- and foresights should be of equal lengths and not exceed 40 m.

b) Check for collimation error which is of particular importance where the sights vary greatly in length.

c) The levelling staves should be of invar, wood or other material in descending order of accuracy.

d) Hold staves vertically with the aid of a bubble.

e) Ensure that the illumination of the staff is sufficient for accurate reading.

f) Ensure that the staff is always placed on a hard surface.

g) Ensure that instrument complies with requirements on minimum focusing.

h) Levelling work should always start and finish on points of known level.

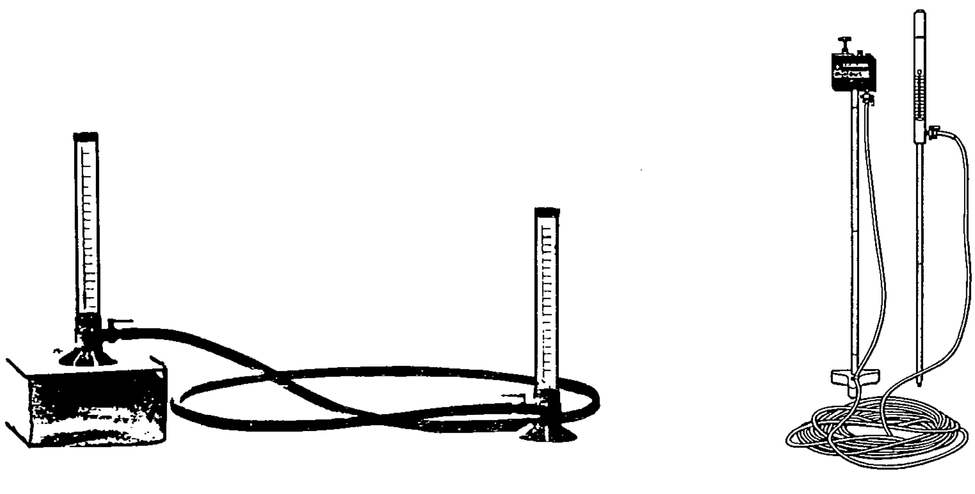


Figure 81

15.10 Micrometer measuring bars

Micrometer measuring bars are used for measuring ranges up to 1 500 mm, for the measurement of internal dimensions where a high degree of accuracy is required. (See figure 82.)

Take into account the following (see also 15.11):

a) Ensure that the bar is not heated by the hands of the operator.

b) Oil only in one place — the micrometer screw, and then only with light oil.

c) If possible use an instrument with a friction screw to avoid undue pressure.

15.11 Micrometer screw gauges

Micrometer screw gauges are used for measuring ranges up to 50 mm. (See figure 83.)

Take into account the following:

a) The lead of the micrometer screw should be 1 mm.

b) There must be provision for adjustment of the zero setting.

c) The spindle should have friction to avoid undue force that could damage the frame.

d) The frame should be fitted with heat insulation.

e) The micrometer must be placed at right angles to the object being measured.

f) The screw must be turned in the same direction until contact is made.

g) Check readings against known sizes.

h) A micrometer should never be stored with its measuring anvils closed.

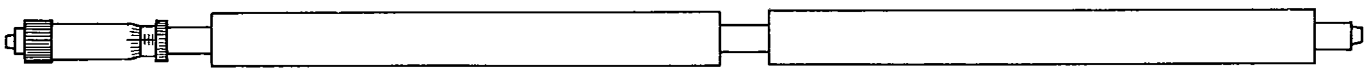


Figure 82

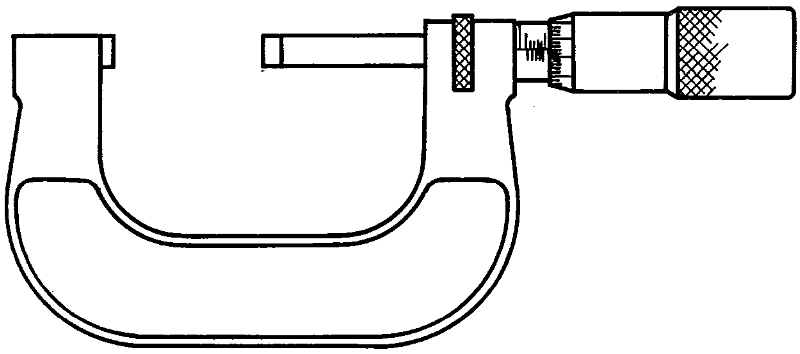


Figure 83

15.12 Measuring magnifiers

Measuring magnifiers are used for the measurement of narrow joints and cracks. (See figure 84.)

Take into account the following:

a) Adjust for the elimination of parallax.

b) Keep the measuring scale as near as possible to the object to be measured.

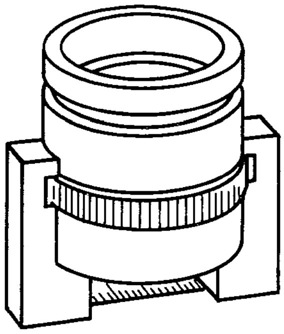


Figure 84

15.13 Measuring rods

These are straight rods of steel or other suitable material of which one edge is graduated to one millimetre, for measuring on surfaces.

Take into account the following:

a) The cross-section of the rod should be such that it gives a minimal parallax error, i.e. a bevelled section is preferable to a square section.

b) If the zero mark is at the end of the rod, errors can arise due to wear.

c) If a rod is longer than 1 000 mm, it should be supported on at least three points during the measuring operation.

d) Care is required to ensure that the rod is horizontal.

15.14 Telescopic measuring rods

Telescopic measuring rods are used for horizontal, vertical or diagonal measurements between surfaces or points up to 5 m apart. Several types are available.

Take into account the following:

a) When measuring vertical or horizontal distances, use a rod that has a bull's eye level attached to avoid having the rod out of plumb or sloping.

b) Wear on the contact surface can allow inaccuracies. Check frequently against a known distance.

15.15 Measuring wedges

Measuring wedges are used for the measurement of width of joints on or near surfaces. (See figure 85.)

Take into account that agreement is required on where along the joint the measurements are to be carried out.

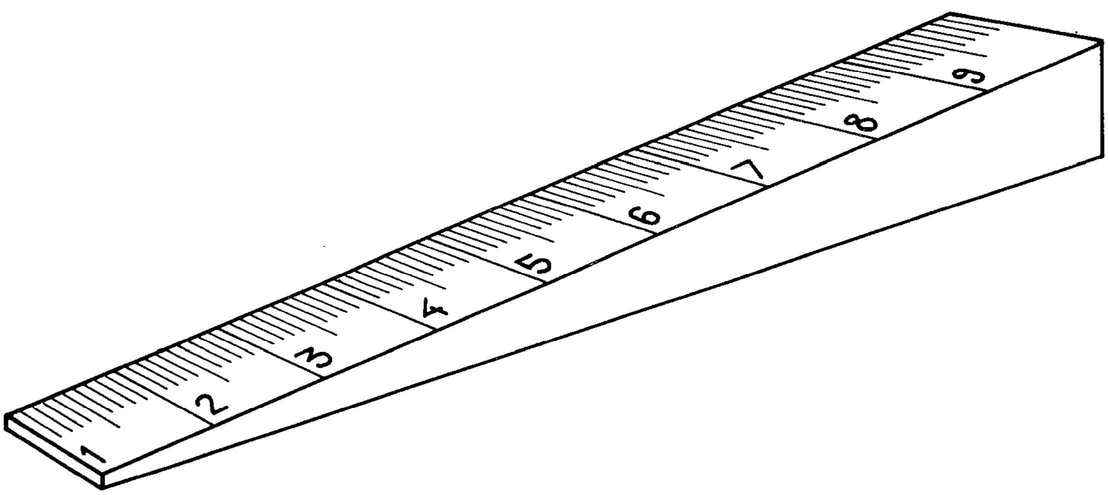


Figure 85

15.16 Optical plumbing instruments

Currently three types of optical plumbing instruments are available — those which plumb downwards only; those which plumb upwards only; and those which plumb both upwards and downwards.

Take into account the following:

a) When plumbing with instruments that have no compensators, measurements should be made in four positions at right angles to each other.

b) If the instrument has one compensator, readings should be made in two positions at right angles to each other.

c) If the instrument has two compensators, only one reading is necessary, but two are preferable.

d) Upwards plumbing requires extreme caution from the safety point of view.

e) Refraction can cause errors when measuring close to a façade.

f) The use of optical plumbing instruments should only be entrusted to trained personnel.

15.17 Plumb bobs

Plumb bobs are used to define a vertical reference line.

Take into account the following:

a) Air currents can cause serious errors, especially for long plumb lines (> 3 m).

b) Bobs should be of sufficient mass (> 1 kg) to ensure reasonable stability of the line.

c) Immersion of the bob in oil reduces vibration but does not overcome effects of air and wind movements. Be extremely careful to avoid spillage of oil on the floor.

15.18 Position pieces

Position pieces are used for defining corners and edges of products like concrete, where there is a distinct surface texture or liability to damage of corners and edges. Special pieces are available for inward-facing corners. (See figure 86 for some examples of position pieces.)

Take into account the following:

a) The pieces should be pressed against the surface of the object of measurement in a manner which ensures that they will not be dislodged during measuring operations.

b) Where necessary, use measuring pegs for securing tapes, rules, anchorages for strings, etc.

c) Ensure that measuring pegs, supports and similar pieces in simultaneous use are all of the same dimension.

15.19 Right-angle prisms

These are optical, hand-held tools for rough setting-out or checking right angles.

Take into account the following:

a) There is no means of adjusting this tool. Check accuracy against a well-defined right angle.

b) Angle mirrors are not recommended.

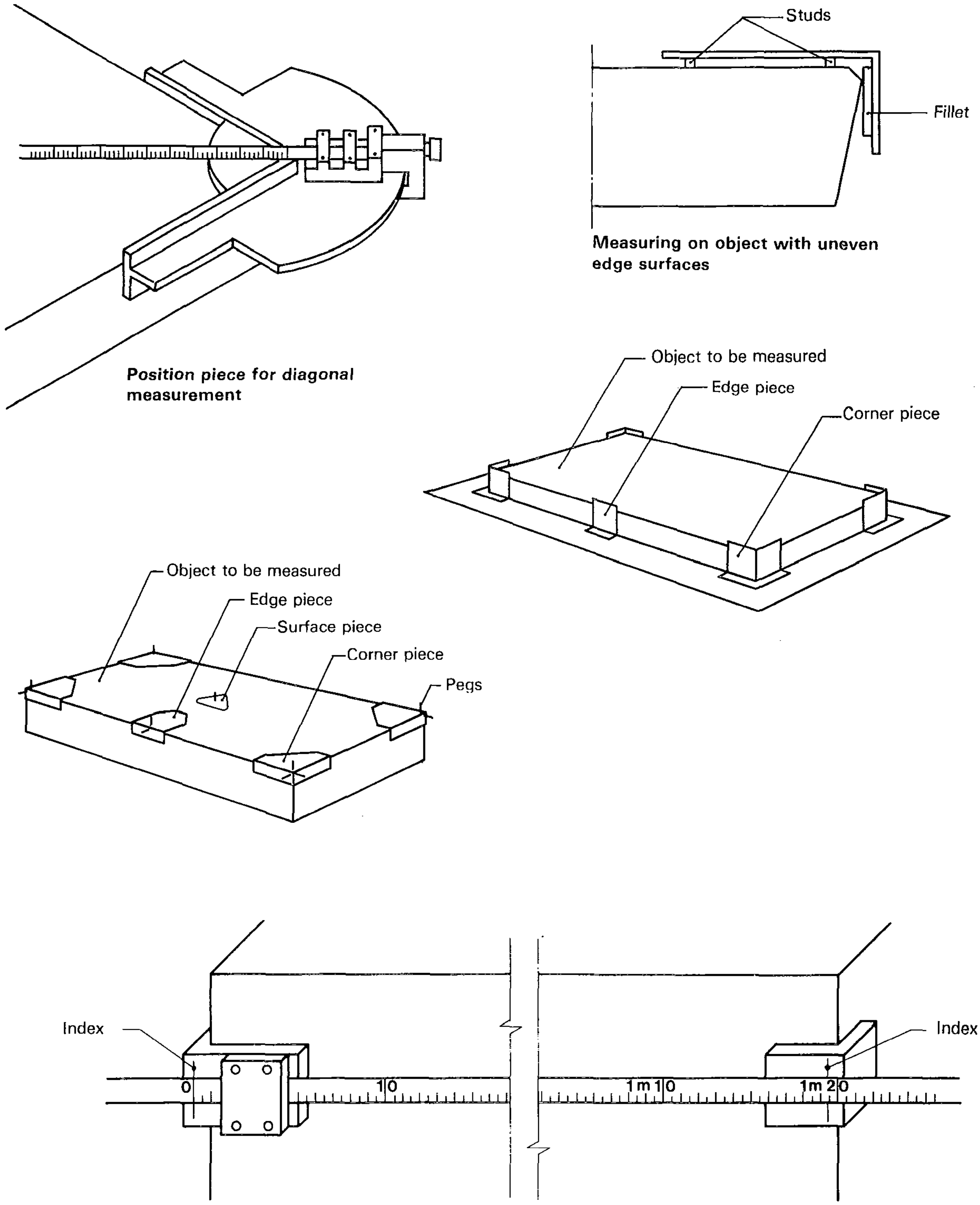

Studs
Fillet
Measuring on object with uneven edge surfaces
Position piece for diagonal measurement
Object to be measured
Edge piece
Corner piece
Object to be measured
Edge piece
Surface piece
Corner piece
Pegs
Index
Index
0
10
1m10
1m20

Figure 86

15.20 Squares

These are L-shaped tools preferably of steel, used primarily for checking right angles.

Take into account the following:

a) If necessary, measuring points should be defined with position pieces.

b) The arms of the square should be not longer than 1 200 mm.

c) The angle to be checked should be rechecked by reversal of the square.

A method of testing a square is to stand it on a surface plate and scribe a fine line along the vertical surface of an object standing on the same plate. The base of the square is now reversed from left to right or vice versa and another line scribed very close to the first one. Any error of angle between the arm and its base will at once be revealed by an examination of the two lines. (See figure 87.)

15.21 Straightedges

Straightedges are used to provide a line from which to measure straightness deviations.

Take into account the following:

a) Supports of equal length should be provided near the ends of the bar.

b) They should be frequently checked for straightness by reversal or use of a stretched wire or thread.

15.22 Retractable steel pocket tapes

These are used for the direct measurement of dimensions and distances up to 5 m and are usually graduated in millimetres throughout. This kind of tape is provided with an enclosing case.

Take into account the following:

a) Movement of the L-shaped edge at the zero mark should be checked.

b) They should not be used to measure distances in excess of their own lengths.

c) They should be cleaned and oiled frequently to avoid blockage of the return spring.

15.23 Steel tapes

Steel tapes should conform to national standards or OIML recommendations. Tapes can be used for direct measurement of dimensions and distances up to 100 m but it is preferable to limit the range to 50 m. Accuracy can be improved by applying the right tension and corrections for slope, sag and temperature. (See the annex for relevant formulae.)

Take into account the following:

a) Accuracy deteriorates with use and tapes should therefore be checked frequently against a reference tape or established reference marks. For tapes used daily this checking should be not less frequent than monthly.

b) Tapes which have been repaired should not be used for check measurements or for collecting accuracy data, unless they have been calibrated after repair.

c) After each day's use, tapes should be cleaned and oiled lightly to prevent rusting and to retain legibility.

d) The ring fixing at the start of the tape should be checked to identify the zero of graduations (practice differs between manufacturers).

e) Care is required in applying corrections.

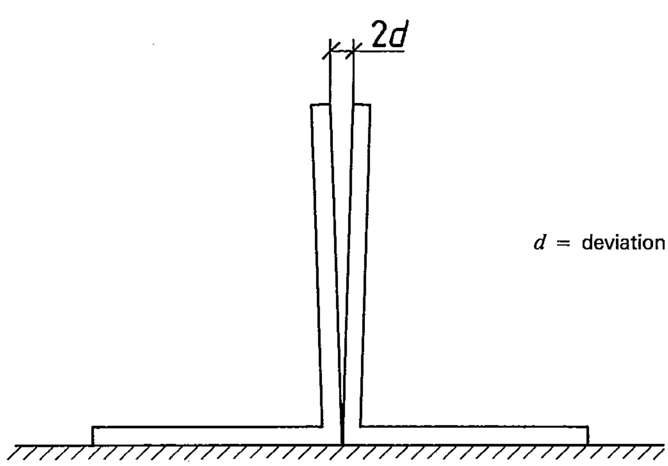


Figure 87

f) The characteristics of the tape concerning temperature and tension must be known.

g) The tape must be allowed to reach ambient air temperature. The temperature of the tape should be measured with the aid of a contact thermometer.

h) The temperature of tapes supported over their whole length can depend largely upon that of the supporting material.

i) Keeping unused tapes in strong sunlight should be avoided.

15.24 Targets (aiming targets)

These are ancillary equipment used to indicate the position of the points to be observed. (See figure 88.)

Take into account the following:

a) There should be good contrast between the target and its background.

b) Be careful to observe the correct target and to observe it at its bisection.

c) For highest accuracy, targets should be placed on tripods or fixed as permanent marks.

15.25 Theodolites

Theodolites are used for the measurement, setting-out and checking of horizontal and vertical angles, lines and planes. They can be provided with a diagonal eyepiece for vertical or near-vertical sights.

Take into account the following:

a) Always use both faces of the instrument with a traditional theodolite.

b) Check the adjustment of the optical plumbing unit.

c) Ensure stability of the tripod and shade from undue effects of the sun.

d) Do not construct long lines by prolonging short ones.

e) Check periodically for collimation and other sources of instrument maladjustment.

f) Protect bubble vials of the theodolite against the sun.

g) Investigate whether a focusing error exists when focusing from long to short (or vice versa). When possible, keep the maximum focusing distance larger than 10 m.

15.26 Tripods

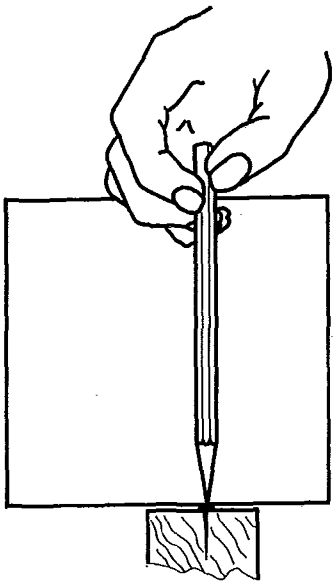
Tripods are used to support instruments and targets. Basically there are two types, rigid tripods and telescopic ones, the legs of which are extendable.

Take into account the following:

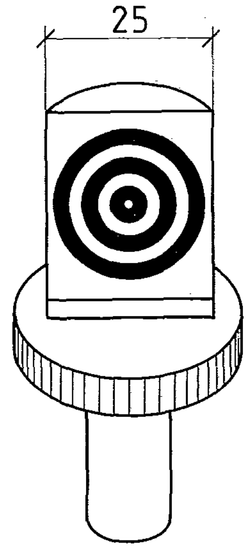
a) The stability of tripods should be checked frequently. Check that connections between tripod head and legs are secure, extendable legs are tightened sufficiently and that metal shoes at the base of each leg are not loose.

b) Tripods subject to large thermal movements, especially some light metal tripods, should not be used in direct sunlight.

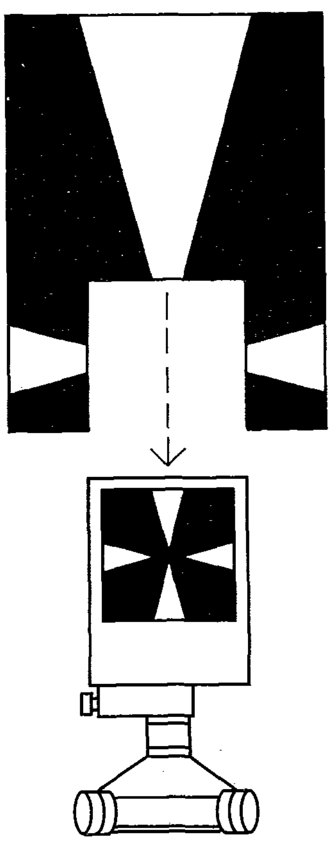
Dimensions in millimetres



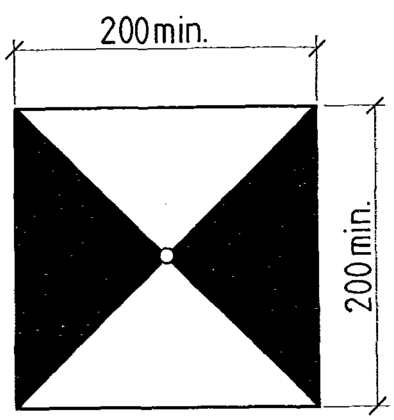
Fine nails or pencil points can be used as targets for distances up to 30 m



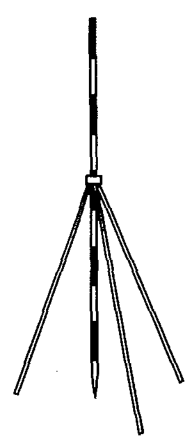
Special targets to be placed on tripods or in permanent marks, for distances between 5 and 20 m, when high accuracy requirements are required



Traverse targets for distances between 20 and 500 m. For distances over 500 m, an extra aiming plate should be added to the target



Aiming targets on a wall for distances between 20 and 1 000 m



Range rods (if straight) for distances between 200 and 1 000 m

Figure 88

Annex

Tape corrections

(This annex forms part of the Standard.)

A.1 Sag correction

When a tape is unsupported, it will sag into a catenary between its two ends so that the measured distance is greater than the real distance between the end points.

The sag correction, C_s, in metres, can be calculated as follows:

$$C_s = \frac{L^3 m^2}{24 t^2} \cos^2 \alpha$$

where

L is the length of catenary in metres;

m is the mass of tape in kilograms per metre;

t is the tension in newtons;

α is the vertical angle between the sloping chord joining the ends of a tape and the horizontal.

The appropriate tension shall be applied. This can be achieved by using a tape tensioner or a spring balance.

A.2 Temperature correction (to adjust for expansion or contraction)

Changes in the length of a steel tape or band due to thermal movement can cause significant errors when the tape temperature differs by more than 5 °C from the standardized value, normally 20 °C.

For steel tapes the correction, C_{temp}, is as follows:

$$C_{temp} = L\, a\, \Delta t$$

where

L is the measured length;

a is the coefficient of expansion per °C (0,000 011 or 11×10^{-6} for steel);

Δt is the difference from calibration temperature;

$$\Delta t = t_m - t_c$$

in which

t_m is the measured temperature;

t_c is the calibration temperature.

The temperature of tapes in catenary is often close to the air temperature. However, when a tape is supported over its whole length its temperature can then depend largely upon that of the supporting material which implies that it will be difficult to determine the temperature of the tape.

In this situation the tape should be insulated from the surface by supporting it on wooden blocks at intervals of a few metres, thus allowing the air to circulate around it.

Taping and keeping unused tapes in strong sunlight should for similar reasons be avoided.

It is preferable that the actual temperature of the tape be measured with the aid of a contact thermometer.

A.3 Slope correction (to give a horizontal length)

Even on small slopes, differences in level between points to be set-out can cause errors which could be significant. Over short distances these can usually be corrected by holding the tape approximately horizontal. However, over greater distances improved accuracy will be obtained by taping on the slope and applying the appropriate correction.

The correction, C_{slope}, in metres, is as follows:

$$C_{slope} = -L\,(1 - \cos \alpha)$$

or, when the difference in level is small:

$$C_{slope} = -\frac{h^2}{2L}$$

where

L is the measured length in metres;

α is the vertical angle between the sloping chord joining the tape ends and the horizontal;

h is the difference in level, in metres, between the tape ends.

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